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DURABILITY TESTING AT 5 ATMOSPHERES OF ADVANCED CATALYSTS AND CATALYST SUPPORTS FOR GAS TURBINE ENGINE COMBUSTORS

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Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
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Washington, D.C. 20545
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Abstract

Studies were conducted under a NASA contract funded by DOE to experimentall demonstrate the durability of CATCOM* catalysts and catalyst supports in a combustion environment under simulated gas turbine engine combustor operating conditions.

A test of 1000-hours duration was completed with one catalyst using #2 diesel fuel and operating at catalytically-supported thermal combustion conditions. This five-atmosphere pressure durability test was conducted using an air-preheat temperature of about 640°K and a reference velocity of about 14 meters/second. The adiabatic flame temperature of the fuel/air mixture was 1533°K. The performance of the catalyst was determined by monitoring emissions throughout the test, and by examining the physical condition of the catalyst core at the conclusion of the test. Tests were performed periodically to determine changes in catalytic activity of the catalyst core. Detailed parametric studies were also run at the beginning and end of the durability test, using No. 2 fuel oil. Initial and final emissions for the 1000-hours test respectively were: unburned hydrocarbons (C_3 vppm): 0, 146; carbon monoxide (vppm): 30, 2420; nitrogen oxides (vppm): 5.7, 5.6.

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*CATCOM is a tradename of Engelhard Minerals & Chemicals Corporation.

I. SUMMARY

The objective of the NASA contract NAS3-19416 was to experimentally determine the durability of a CATCOM* catalyst (identified as DXE-442) in a combustion environment at five-atmospheres pressure. A 1000-hour life test was conducted using #2 diesel fuel and operating at catalytically-supported thermal combustion conditons. The contract was funded by the U.S. Department of Energy and managed by NASA/Lewis.

The life test was conducted at simulated gas turbine steady state operating conditions using an air-preheat temperature of 640°K, a catalyst inlet reference velocity of 14 M/S, and an adiabatic flame temperature of the fuel/air mixture of 1533°K.

The performance of the catalyst core was determined by monitoring emissions of UHC, CO, and NO_x throughout the life test and by examining the physical condition of the catalyst core at the conclusion of the life test. Scheduled activity tests were performed periodically during the life test to determine changes in catalytic activity. In addition, parametric tests using #2 diesel fuel were performed at the beginning and the end of life testing. The range of parametric test conditions studied included pressures of 1×10^5 N/M^2 to 5×10^5 N/M^2, air-preheat temperatures of 663°K to 723°K, reference velocities of 14 M/S to 26 M/S, and adiabatic flame temperatures of 1366°K to 1533°K.

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*CATCOM is a tradename of Engelhard Minerals and Chemicals Corp.

These studies were carried out in a test rig designed and constructed for continuous elevated pressure testing under the contract. The key component of this rig is a nominal one-inch diameter tubular reactor in which the catalyst was mounted and which was operated downflow at essentially adiabatic conditions.

At the end of 1000 hours of operation with #2 diesel oil, there was no apparent physical degradation of the catalyst support. Initial and final emissions during the 1000-hour test were:

	Initial After 63 hrs	After 1014 hrs	After 1062 hrs
Unburned Hydrocarbons (C_3 vppm)	0	146	0
Carbon Monoxide (vppm)	30	2420	35
Nitrogen Oxides (vppm)	5.7	5.6	4.3

Following the 1000-hour test, the catalyst activity was apparently partially regenerated after an unplanned 48 hour, 673°K air soak while analytical system repairs were made. Thus, the catalyst deactivation which was observed to occur gradually during the 1000-hour test was reversible.

It was apparent, however, the DXE-422 catalyst performance during the 1000-hour, five-atmosphere life test was not as good as the performance of previous catalyst test cores DXB-222, DXC-532 (1), or the same DXE-442 after 1000-hours life testing at one-atmosphere pressure. This was a

surprising result since the five-fold increase in convective heat transfer at five atmospheres relative to one atmosphere was expected to generate lower surface temperatures in the front portions of the catalyst. However, an initial operational problem with the fuel injection system resulted in numerous high catalyst inlet temperature exposures which may have caused premature de-activation of kinetic (ignition) activity. This operational problem was resolved by changing the method of fuel injection and mixing, but may have been too late to preserve high performance kinetic activity.

II. INTRODUCTION

2-1. DURABILITY TESTING AT ONE ATMOSPHERE (PREVIOUSLY REPORTED IN REFERENCE 1)

The concept of using catalysts for low emission combustion processes has been intensively explored by Engelhard Industries Division of Engelhard Minerals and Chemicals Corporation over the past eight years. Laboratory tests have shown the feasibility of low emissions operation, particularly NO_x emissions, with a wide variety of gaseous and liquid fuels(2,3). Rig tests at NASA Lewis, Westinghouse and Wright Patterson Air Force Base have confirmed these laboratory results, and also showed the ease of scale-up and improved temperature pattern factor for catalysts (4,5,6).

NASA Lewis Research Center realized that information on the durability of the catalyst and catalyst support in the extreme conditions of a combustion environment was required to further demonstrate the practicality of candidate CATCOM catalysts. In addressing this question, the NASA contract NAS3-19416, entitled "Catalyst and Catalytic Substrate Material for Gas Turbine Engine Combustion" was awarded to Engelhard Industries on March 21, 1975. The period of performance of this early contract was 18 months. Under this contract relevant information was to be obtained on the long term operation capabilities of CATCOM catalysts. This contract was funded by ERDA and managed by NASA/Lewis.

The program under this contract was divided into three tasks. Task I of the contract required selection of catalyst cores for endurance testing, based on catalyst screening results at Engelhard Industries. Under Task II, a test rig and adiabatic tubular reactor were constructed. Task III involved life testing of two selected catalyst cores. These life tests were conducted at conditions which simulated steady state operation of a gas turbine combustor. Testing was satisfactorily completed on two catalyst cores designated DXB-222 and DXC-532.

The details of this contract, the construction of the test rig, the performance test results and conclusions regarding the durability of the catalyst cores are discussed in the report NASA CR-135132 issued under the title: "Durability Testing at One Atmosphere of Advanced Catalysts and Catalyst Supports for Automotive Gas Turbine Engine Combustors" in June, 1977 (1).

The results were also presented under the same title at the 70th Annual Meeting of the American Institute of Chemical Engineers on November 16, 1977.

2-2. DURABILITY TESTING AT FIVE ATMOSPHERES

Because all potential commercial applications for gas turbine engine combustors entail operation at elevated pressure levels, a follow-on program was established under the contract NAS3-19416 to carry out durability testing at 5 atmospheres pressure. The experimental test rig used in the early studies was modified to allow extended operation at elevated pressure using a more sophisticated control and safety system. Catalyst selection for this program was made on the basis of prior Engelhard experience and work done under the initial 1 atmosphere test portion of the NAS3-19416 contract. The catalyst core identified as DXE-442, was chosen for the program since it was the best existing prospect for extended life, potentially higher temperature stability, and commercial viability. One atmosphere life test data for DXE-442 catalyst is presented in Section 5-6. Engelhard test results indicated that DXE-442 represented an improvement in performance over DXC-532 and equivalent performance to DXB-222, both of which were successfully tested in the 1 atmosphere portion of the NASA program. The follow-on program was divided into three tasks as follows:

Task IV - Test Rig Modification Design, Fabrication, Construction, and Precommissioning (including provisions for safe continuous high pressure high temperature operation and control).

Task V - Sub-Scale Catalytic Substrate Parametric and Endurance Testing.

Task VI - Reporting Requirements

Based on the experience developed in the 1 atmosphere studies, the original scope of the work was reduced to obtaining the key data desired.

III. Task IV - TEST RIG MODIFICATIONS

In order to carry out the experimental program described in Task V, the test rig constructed for the one atmosphere life test under Task II of the contract had to be modified to allow safe, unattended operation at five atmospheres pressure. The test capabilities of the unit previously described in the Test Facilities section of the one atmosphere report had to be broadened. A simplified schematic of the modified NASA test rig is presented in Figure III-1. Photographs of the test rig and the control panel equipment are shown in Figures III-2 and III-3. A detailed drawing of the reactor is given in Figure III-4.

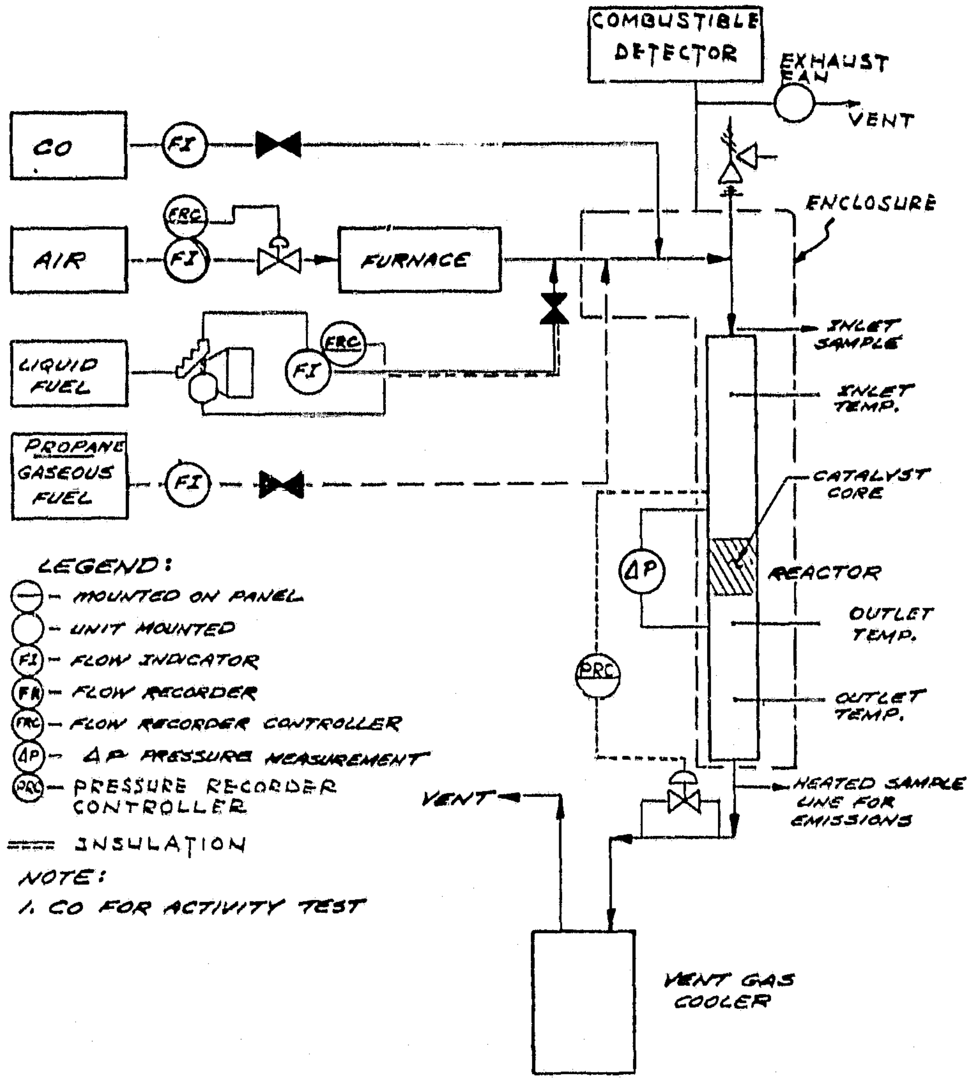
The equipment modifications can be broken down to three major categories:

A. Safety System

B. Process Control System

C. Fuel Presentation System

Figure III-1: Schematic of Modified Test Rig



BLOCK DIAGRAM OF TEST UNIT
NASA CONTRACT # NAS 3-19416

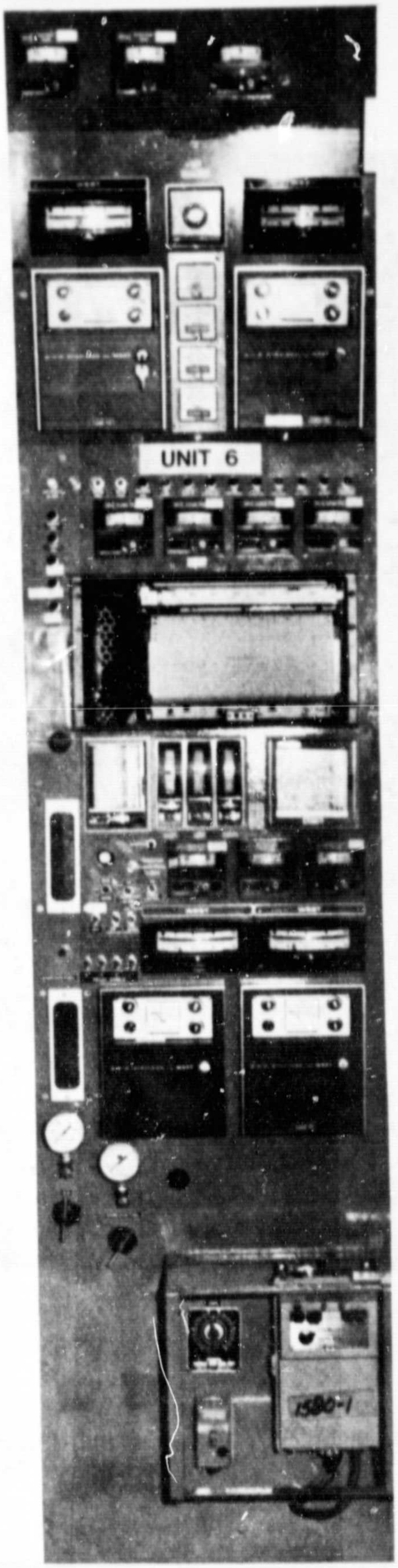


Figure III-2

Photograph of Control
Panel For Unit 6
Test Rig.

Figure III-3 Photograph Showing Phys'cal Layout of Equipment For Unit 6 Test Rig

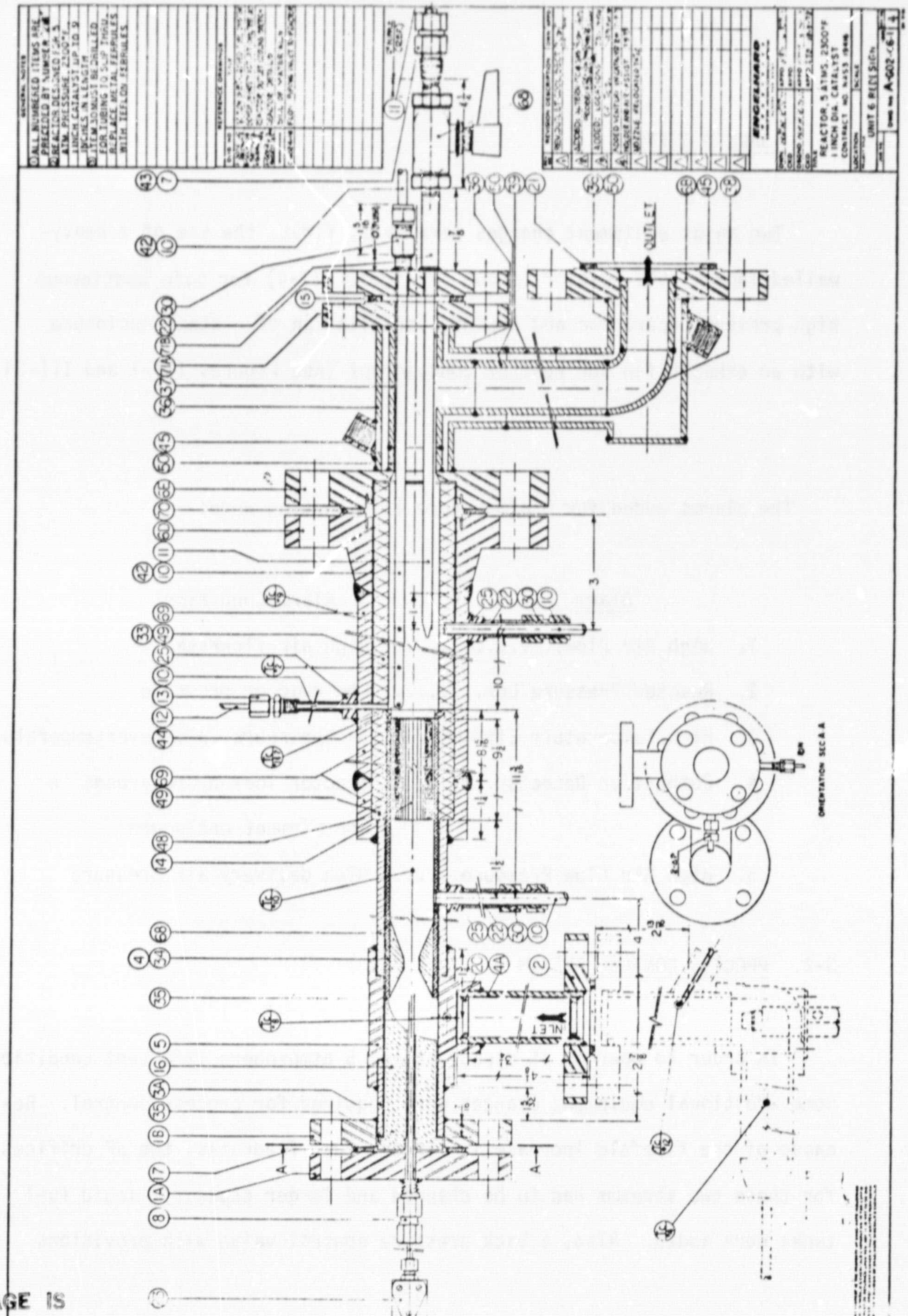


FIGURE III-4

Unit 6 Reactor

3-1. SAFETY SYSTEM

Two major equipment changes were made, first, the use of a heavy-walled Inconel 601 reactor (shown in Figure III-4) for safe continuous high pressure operation and second, installation of a steel enclosure with an exhaust fan for reactor containment (see Figures III-1 and III-3).

The alarms added for 5 atmosphere life testing were:

	Alarm	Alarm Condition
1.	High Air Flow................	High air flowrate
2.	Reactor Pressure Low.........	Low reactor pressure
3.	High Temperature Effluent	Backpressure valve overtemperature
4.	Combustion Detector..........	Reactor leak-hydrocarbons in containment enclosure
5.	High Air Flow Pressure.......	High delivery air pressure

3-2. PROCESS CONTROL SYSTEM

In order to operate at steady state, 5 atmosphere life test conditions some additional equipment changes were required for process control. Because of the fivefold increase in air and fuel feedrates, the ΔP orifices for these two streams had to be changed and larger capacity liquid fuel tanks were added. Also, a back pressure control valve with provisions

for feedback response and pressure recording was installed. The 590°K operating temperature limit of the backpressure control valve required the use of a larger exhaust gas heat exchanger. It was found that exhaust gas cooling using water injection upset the backpressure control loop causing unacceptable reactor pressure oscillations up to $\pm$ 5 psig. The heat exchanger reduced this to less than $\pm$ 1 psig.

One critical problem which had to be resolved involved the location of a low air pressure switch. On occasions when a significant drop in delivery air pressure occurred, this switch (when located downstream of the air orifice) could not respond rapidly enough to this process upset. To prevent an instantaneous fuel rich overtemperature condition, caused by loss of air flow, the sensor was relocated upstream of the air flow orifice where satisfactory response was achieved.

The experimental reactor used in testing the catalyst cores at combustion conditions is constructed of corrosion-resistant heavy-walled Inconel 601 pipe and designed for long term endurance testing at 1533°K and 5×10^5 N/M^2 (5 atm) and short term testing at 1533°K and up to 10×10^5 N/M^2 (10 atm). The reactor was instrumented for measurement of:

- catalyst core inlet and outlet temperature
- catalyst core pressure drop
- catalyst core inlet pressure
- catalyst core emissions

The pressure drop apparatus consisted of a manometer with pipe tap locations upstream and downstream of the catalyst core in accordance with ASME recommended practice.[7]

The range of operating conditions of the test rig is summarized in Table III-1. Detailed operating procedures used for 5 atmosphere diesel fuel life testing are given in Appendix A.

Emission samples were all taken with a 0.00635M (¼") diameter water-cooled sample probe. The sampling train adhered to SAE Standard ARP-1256. The description of each individual analytical instrument is listed in Table III-2. Other standard operating procedures are the same as reported in Reference 1.

3-3. FUEL PRESENTATION SYSTEM

a) Malfunctions

In the course of carrying out the experimental program using #2 diesel fuel, it was found that high reactor inlet temperature shutdowns

Table III-1

Operating Ranges for Unit 6

Automatic Control Operation:	
Air Flow	1.85×10^{-3} to 5.9×10^{-3} Kg/S
Air Preheat Temperature	Up to 810^{o}K
Fuel Flow (Liquid)	6.7×10^{-5} to 67×10^{-5} Kg/S
Reactor Pressure	1.0×10^{5} N/M^{2} to 5×10^{5} N/M^{2}
Adiabatic Flame Temperature*	Up to 1533^{o}K
Fuel Type	#2 Diesel
Manual Operation:	
Air Flow	1.85×10^{-3} to 66.7×10^{-3} Kg/S
Air Preheat Temperature	Up to 810^{o}K
Fuel Flow (Gaseous)	1.7×10^{-4} to 17×10^{-4} Kg/S
Reactor Pressure	1.0×10^{5} to 5.0×10^{5} N/M^{2}
Adiabatic Flame Temperature*	Up to 1533^{o}K
Fuel Type	C.P. Carbon Monoxide, #2 Diesel

*For conditions of 90% reactor adiabaticity, adiabatic flame temperature may be increased to 1570^{o}K without damage to reactor walls.

Table III-2

Description of Analytical Systems for Emissions

Emissions	Analytical Equipment	Range	Calibration Gas
UHC (as C_3)	Beckman Model 402 Flame Ionization Detector	50,000 Vppm 100 Vppm 10 Vppm	19,000 Vppm C_3H_8 47 Vppm C_3H_8 10 Vppm CH_4
CO	Beckman Model 315B Non-Dispersive Infrared	5,000 Vppm 500 Vppm 50 Vppm	4,000 Vppm CO 400 Vppm CO 10 Vppm CO
CO_2	Beckman Model 315B Non-Dispersive Infrared	15% 3%	10% CO_2 1.5% CO_2 0.5% CO_2
O_2	Beckman Model 742 Polarographic Analyzer	25% 25%	12% O_2 Zero Air
NO/NO_x	Beckman Model 951 Chemiluminescence Analyzer	1,000 Vppm 10 Vppm	600/900 NO/NO_x Vppm 1.8/2.2 NO/NO_x Vppm

occurred repeatedly at 5 atmosphere life test conditions upon extended operation (overnight) with a fuel injection system essentially identical to that used for 1 atmosphere endurance testing. After unsuccessfully attempting to stabilize operating conditions with the existing system, contract expenditures were halted and a series of Engelhard funded tests were carried out to determine the problem cause and make the necessary adjustments to continue the program. Two possible mechanisms of high inlet temperature shutdown were investigated:

1. Flashback/Preburning of Fuel
2. Inadequate Fuel Vaporization/Mixing with Air

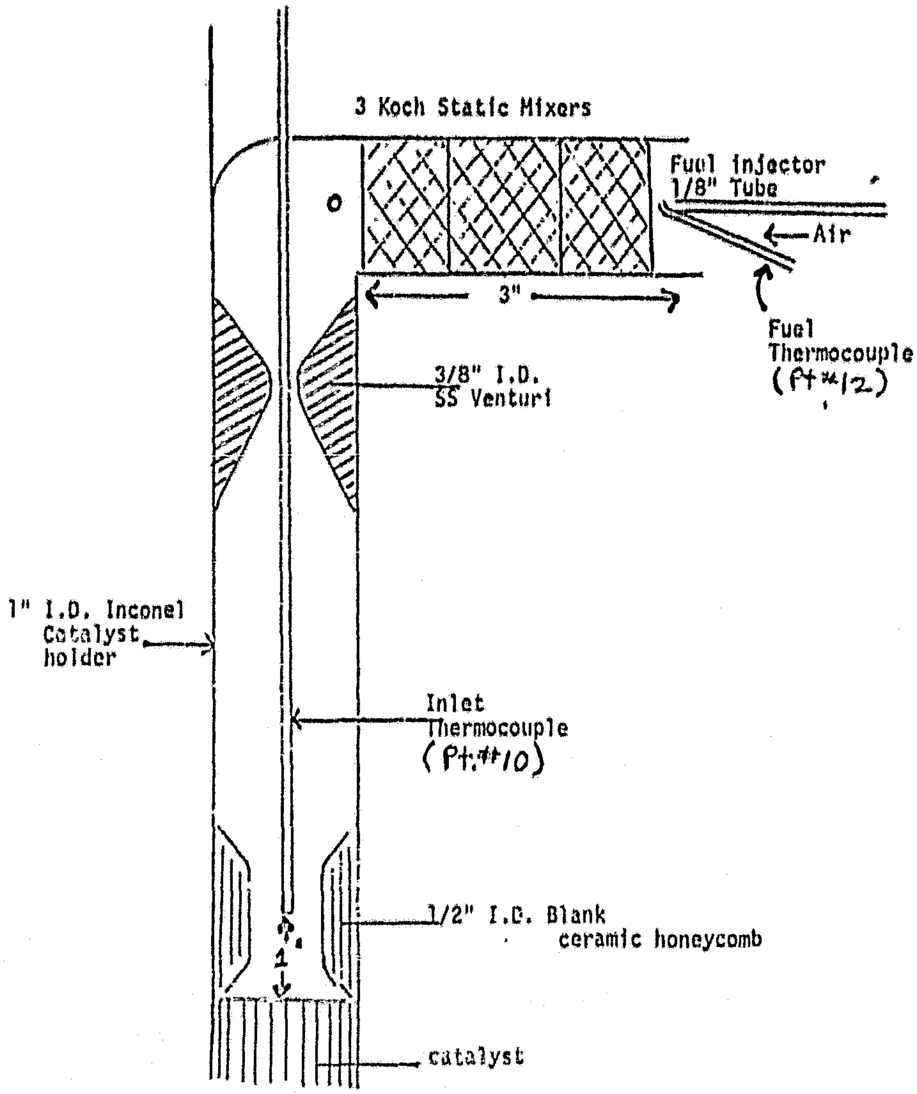
These are described below.

1. Flashback/Pre-burning

Two tests were made in an attempt to retard flashback/preburning. First, a blank honeycomb two inches in length and one inch in diameter was drilled out with a ½" diameter hole and machined to have a venturi taper. It was placed immediately on top of the catalyst inlet face in order to accelerate the flow velocity entering the catalyst and shield the inlet zone from the metal catalyst holder. A schematic diagram is shown in Figure III-5. High inlet temperature shutdowns occurred twice: Once after 4 hours and again after 12 continuous hours on stream.

Figure III-5

Sketch of Flashback Arrestors Tested



Second, a stainless steel venturi section with a 3/8" diameter I.D. was fabricated and installed in the vertical approach piping of the reactor immediately downstream of the horizontal static mixer zone to accelerate flow velocity and thereby retard flashback. A sketch of the venturi location is shown in Figure III-5. A high inlet temperature shutdown occurred after 17 hours on stream with the venturi in place.

2. Fuel Vaporization/Mixing with Air

Since high inlet temperature shutdown could be caused by liquid fuel droplets concentrating in any zone between the injection point and the catalyst inlet face, a more easily vaporized liquid fuel was tested. A high paraffinic Naphtha was used ($C_{7.49}H_{16.24}$), having an end boiling point of $440^{o}K$ (compared to $605^{o}K$ for #2 diesel oil). At standard 5 atmosphere life test conditions, the unit was operated for 24 hours continuously without an inlet temperature shutdown. This had not been accomplished with #2 diesel oil at the same operating conditions. Shutdowns had repeatedly occurred within 3 to 17 hours of startup with diesel fuel.

b) Fuel Injector Modification

From these results, the most probably cause for high inlet temperature shutdowns appears to be the condensation of liquid fuel drop-

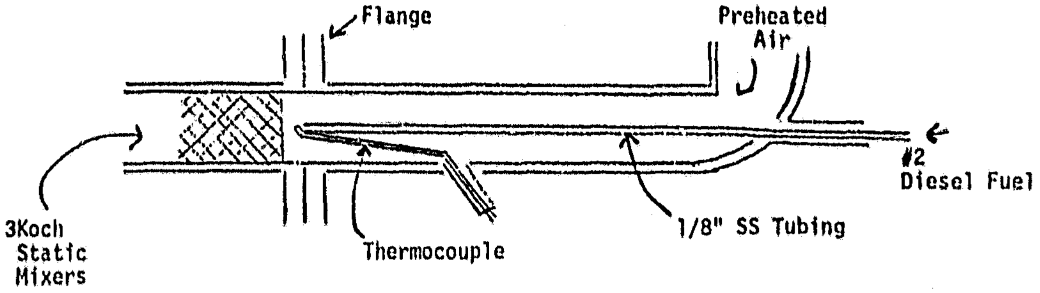
lets in the horizontal piping and static mixer surfaces downstream of the fuel injection point. Once droplet formation occurs, localized fuel concentrations could exist anywhere from the point of condensation down to the catalyst inlet face and, as local flammability limits are exceeded, combustion could be started upstream of the catalyst.

The original fuel presentation system relied upon a 1/8" tube fuel injector positioned immediately upstream of three one inch Koch static mixer elements. The fuel is pre-heated using a length of 1/4" tubing wrapped with electrical heating tape. A thermocouple is installed in the flow piping to measure the liquid fuel temperature directly downstream of the injection point. A sketch is shown on Figure III-6. Effectively the fuel dripped out of the 1/8" tubing at a temperature of 473-573^{o}K and the Koch static mixers were relied upon to completely mix the liquid/air stream before it reaches the catalyst.

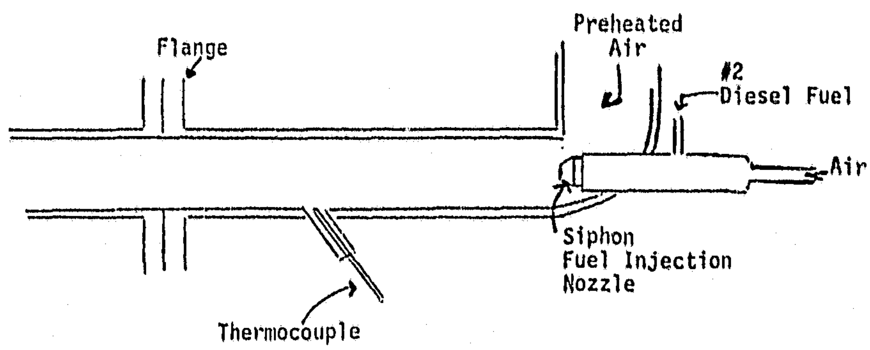
This system had been successfully used for extended periods at atmospheric pressure and for short duration runs (1-5 hours) under pressure. However, when operating at elevated pressures (3-5 atmospheres) for prolonged periods of time, liquid fuel condensation progressively builds up until droplets form and burn upstream of the catalyst, causing high inlet temperatures shutdowns.

Figure III-6

Schematic of Unit 6 Fuel Injection Modification



(a) Existing Liquid Fuel Injection System



(b) New Liquid Fuel Injection System

To improve fuel vaporization and air mixing, an air assisted fuel injection nozzle was installed in the horizontal inlet section of Unit 6. A Delavan air assist siphon fuel nozzle (#30610-2) was used and is rated to generate 10-40 micron diameter fuel droplets. The Koch static mixers were removed and the horizontal pipe was heat traced so the internal pipe wall temperature could be increased if necessary to prevent fuel condensation on the pipe walls. A diagram of the new fuel presentation technique is shown in Figure III-6b.

c) <u>Test Performance of the New Fuel Injector</u>

After making the necessary equipment changes, a continuous run of 90 hours (3.8 days) was made with a duplicate catalyst at 5 atmosphere life test conditions. No pre-ignition or any other safety shutdown occurred using the new air-assisted siphon fuel nozzle. To determine the flashback limit, the inlet temperature at 5 atmosphere life test conditions was increased gradually from 633^{o}K by increasing the air preheat furnace temperatures. At approximately 823^{o}K, the inlet temperature started to climb steadily as flashback occurred. The experiment was repeated and the same result was seen again. At the normal operating inlet temperatures, well below 773^{o}K no flashback or preburning was observed with the new fuel injector.

Prompt resolution of this problem enabled the program to be resumed and completed on schedule and within the budget.

IV. Task V - TEST PROGRAM AND EXPERIMENTAL RESULTS

4-1. LIFE TEST WITH #2 DIESEL FUEL

A 1000 hour durability life test at 5 atmospheres pressure was carried out with the selected CATCOM catalyst core, DXE-442. Commercial grade #2 diesel oil supplied by B.P. Petroleum Co. (analysis in Table IV-1) was used and steady state conditions were maintained for the life test as shown in Table IV-2.

The following data were recorded to monitor catalyst performance during life testing:

- Emission data (CO, UHC and NO_x) - Figures IV-I, 2 and 3.
- CO_2 and O_2 levels in exhaust gas - Figure IV-4.
- Air preheat temperature and catalyst core outlet temperature - Figure IV-5.
- Pressure drop - Figure IV-6.

Detailed computer data reduction printouts of life test results are presented in Appendix B. Major events occurred during life testing are described in Figure IV-7.

Figure IV-1 Carbon Monoxide Emissions Control Chart

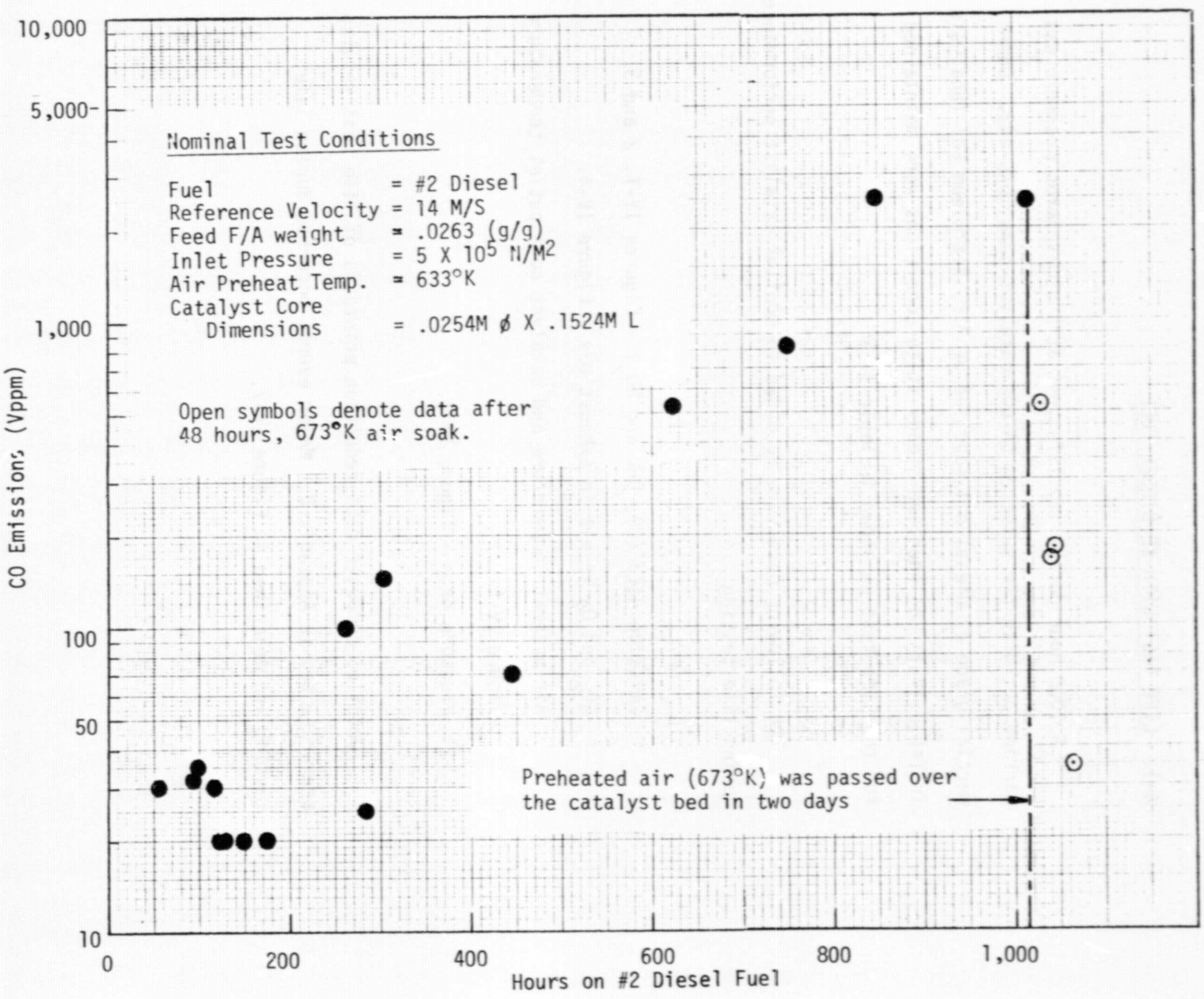


Figure IV-2 Hydrocarbon Emissions Control Chart

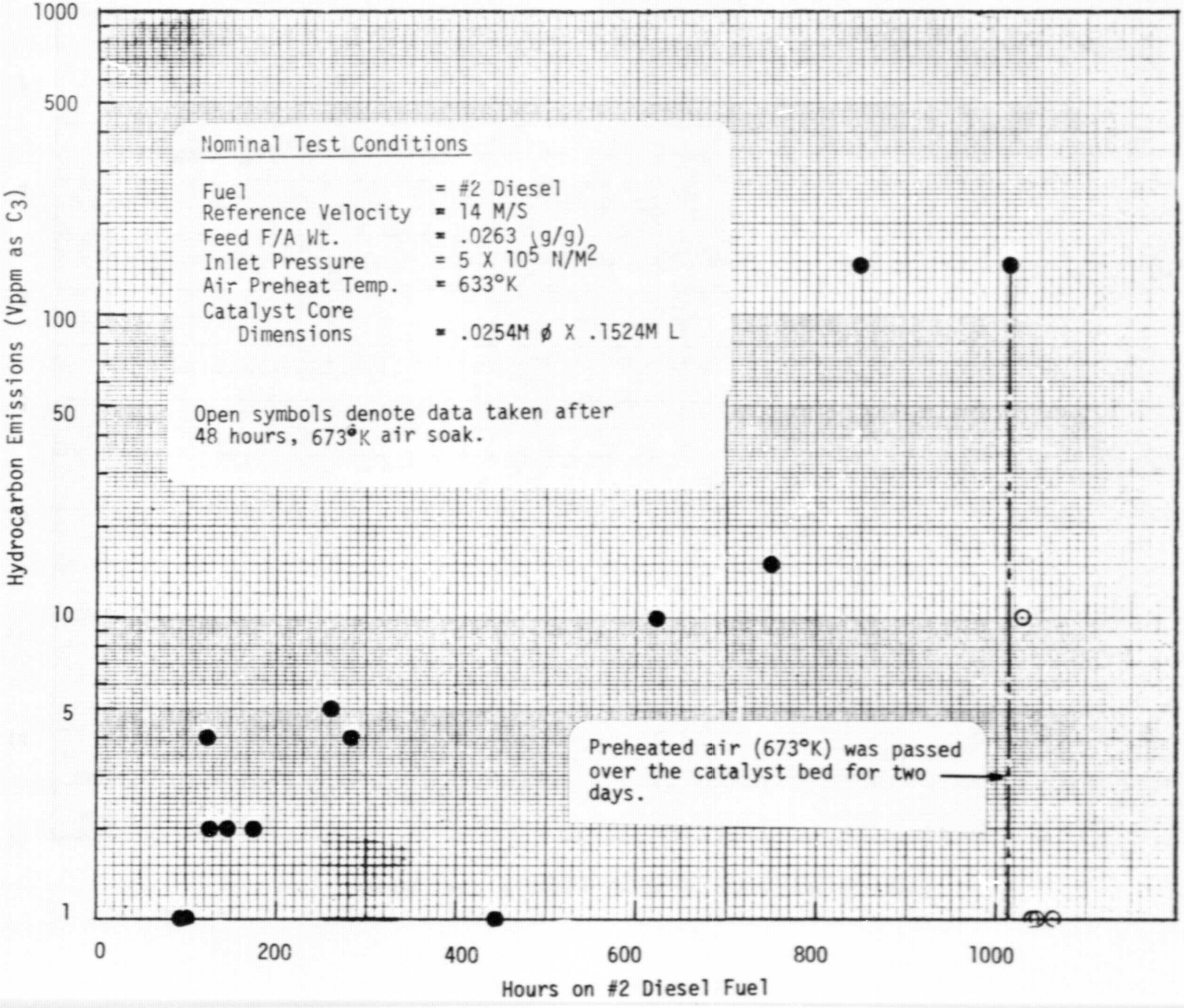


Figure IV-3 Nitrogen Oxide Emission Control Chart

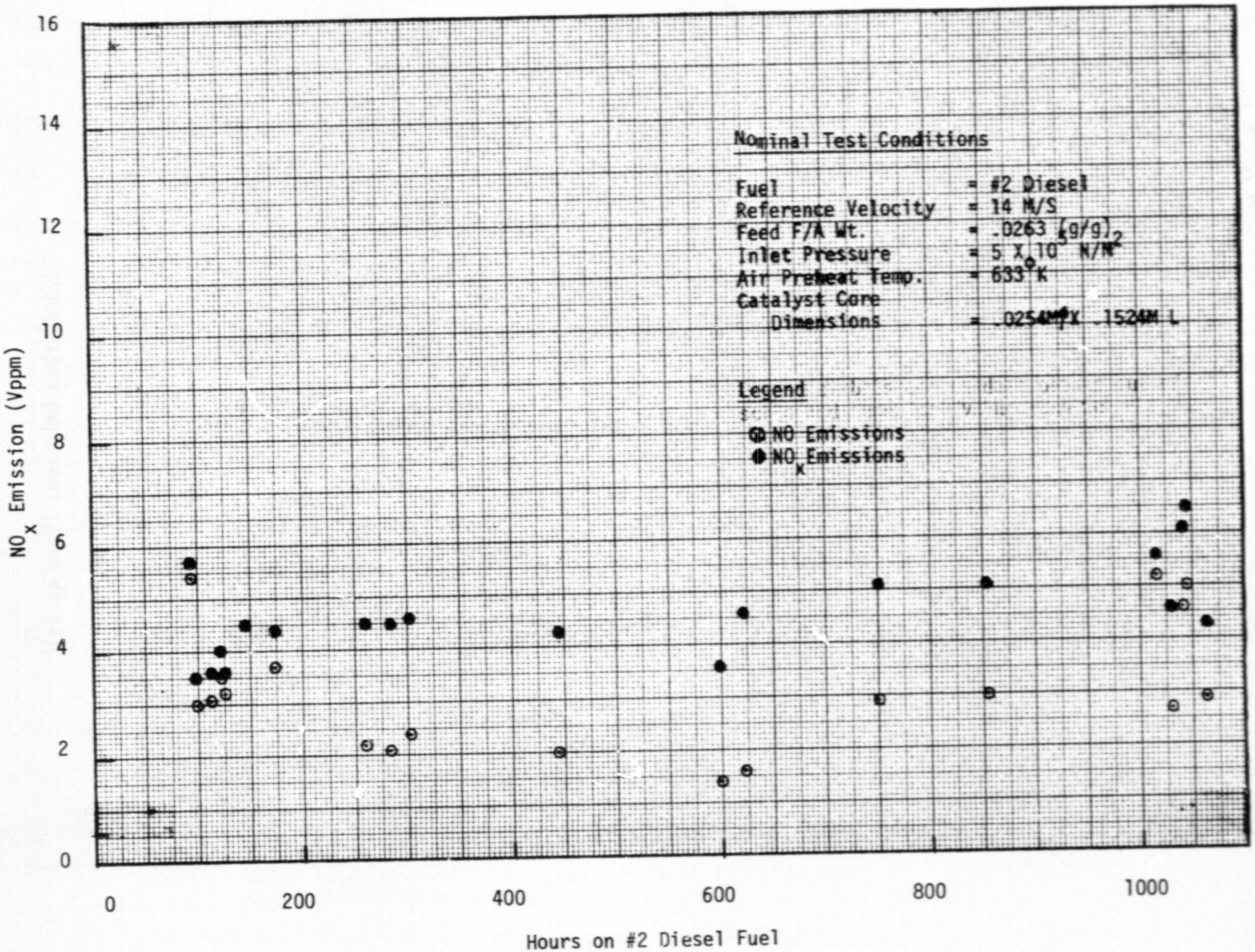


Figure IV-4 Carbon Dioxide and Oxygen Control Chart

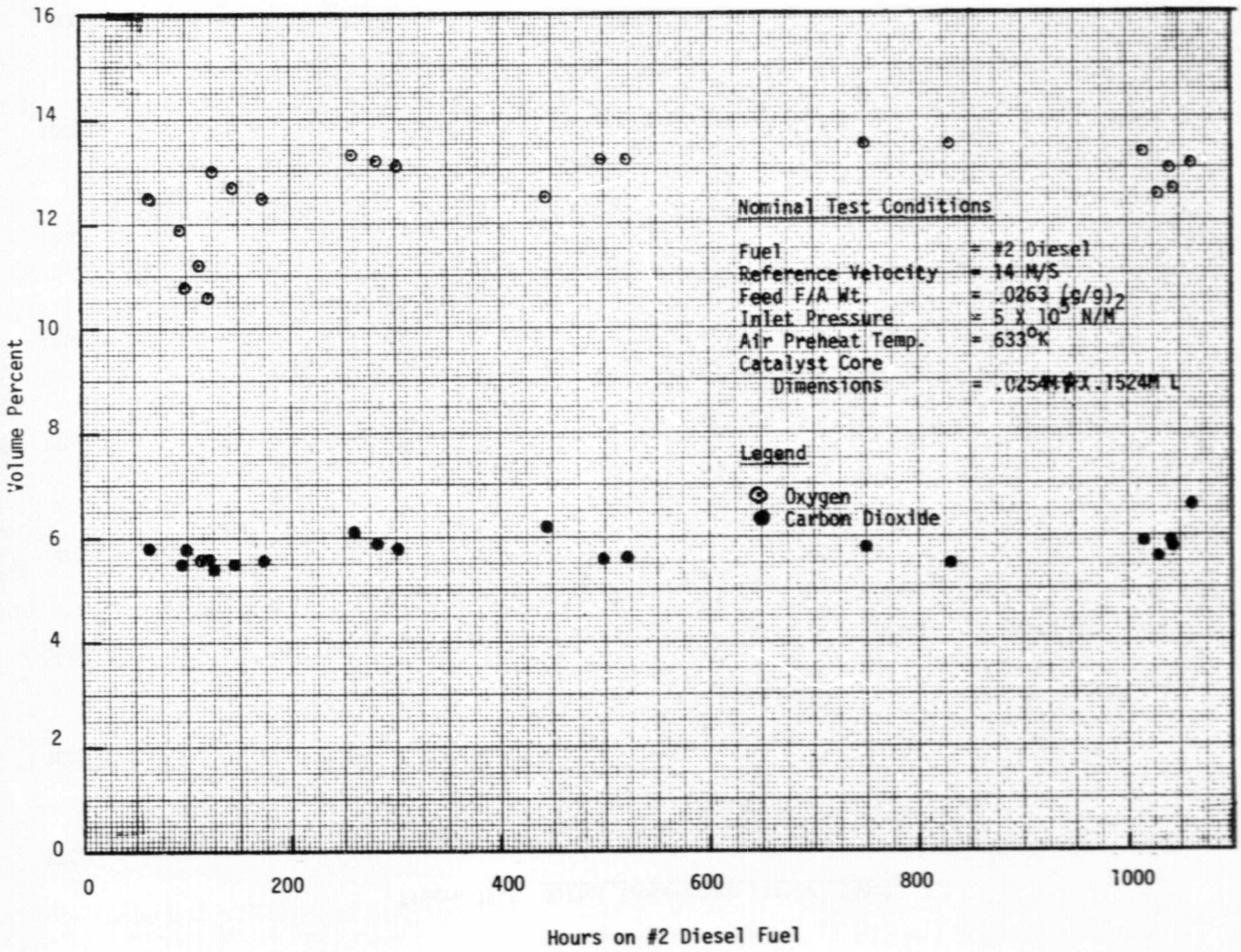


Figure IV-5 Outline Temperature Control Chart

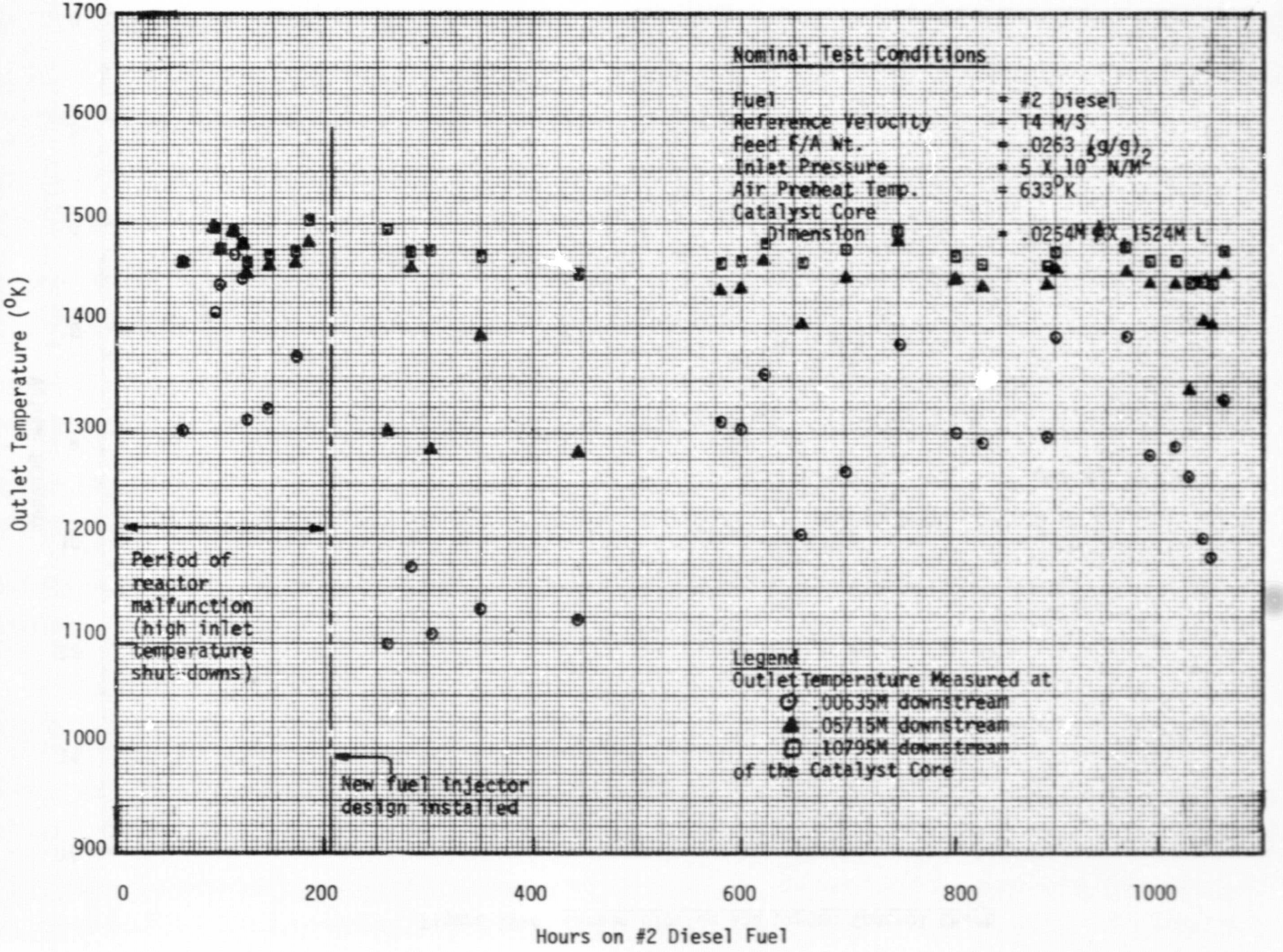


Figure IV-6 Pressure Drop Control Chart

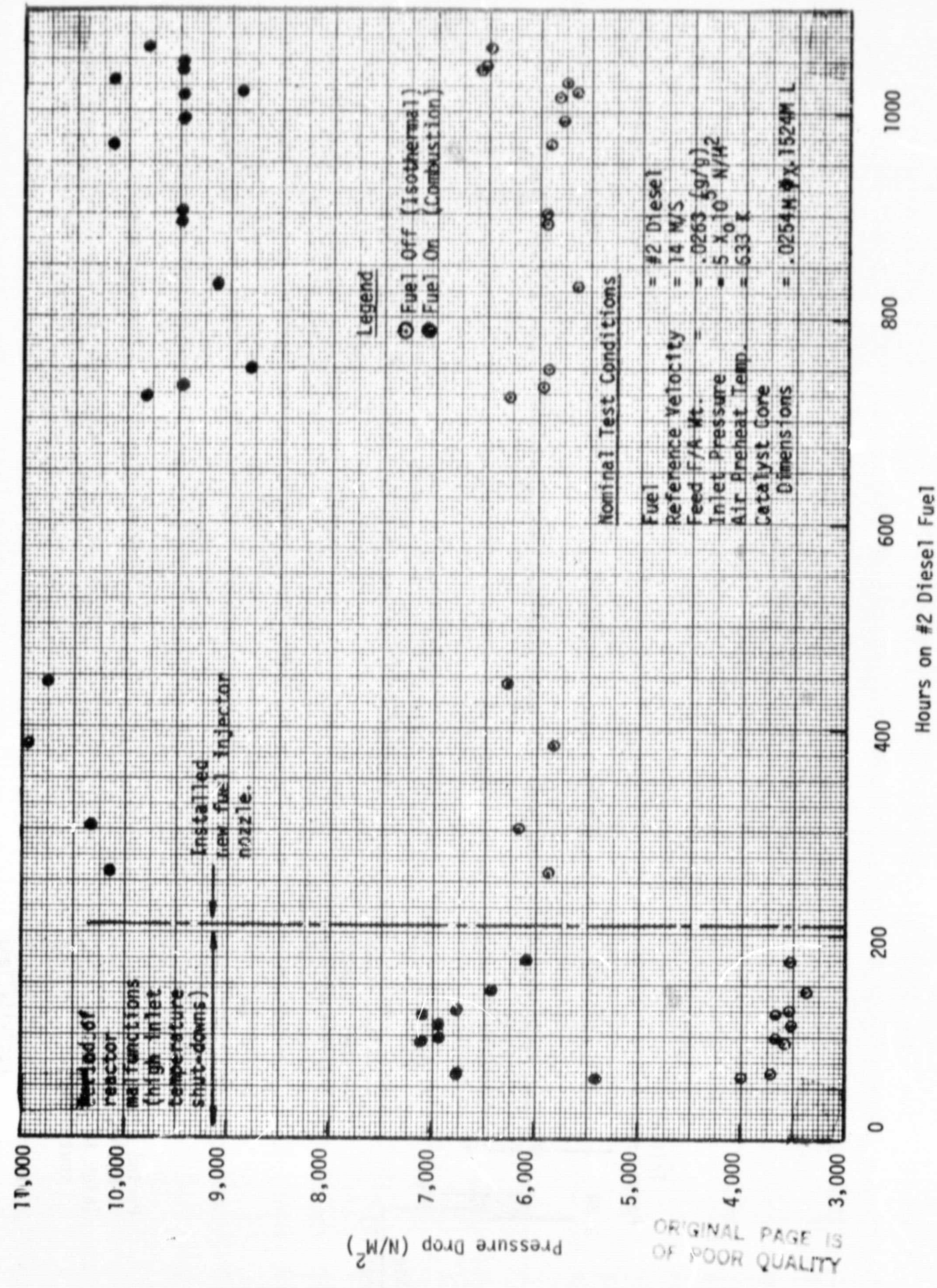
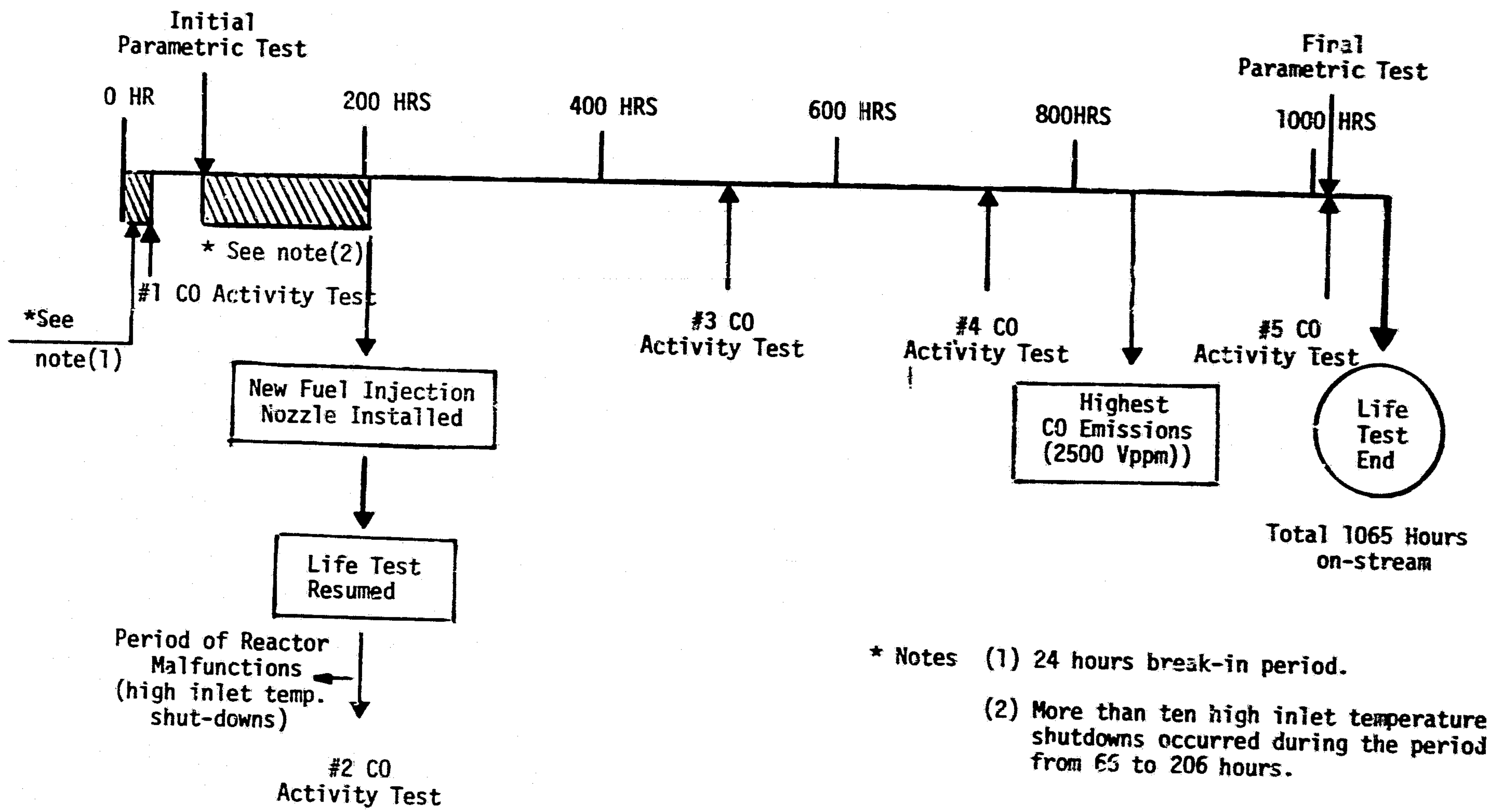


Figure IV-7 Event Chart for the Life Test



Carbon Monoxide Emissions

The CO emissions were constant around 30 Vppm for the initial 200 hours on stream and gradually increased during life testing as shown in Figure IV-1. Two high CO emissions data points greater than 2000 ppm were measured after 848 hours on stream. However, after the final CO activity test at 1014 hours on stream, the CO emissions were significantly lower (525 Vppm) under life test conditions. The CO emissions approached initial performance levels after the catalyst had been maintained around 673°K in the presence of air for two days while a thermocouple was repaired. After this, low CO emissions (less than 200 Vppm) were maintained for 22 continuous hours at the end of the life test.

The average CO emissions were 252 Vppm during life testing. Two high CO emissions data points at 848 and 1014 hours on stream were not used in this average because they are not considered representative of overall catalyst performance.

Unburned Hydrocarbon Emissions

The unburned hydrocarbon emissions exhibit the same trend as the CO emissions (shown in Figure IV-2).

Nitrogen Oxides Emissions

The NO_x emissions varied from 3.5 Vppm to 6.5 Vppm during life testing as plotted in Figure IV-3. Low NO_x emissions were observed especially before 200 hours on stream and it leveled off around 4.8 Vppm during the remainder of the life test. Also it appears that the ratio of NO to NO_x significantly declined after 200 hours on stream as shown in Figure IV-3, and this chronologically corresponds to a change in the liquid fuel presentation system.

Carbon Dioxide and Oxygen in the Exhaust Gas

Plots of CO_2 and O_2 measured in the exhaust gas indicate they were essentially constant over the entire test period, as shown in Figure IV-4. Assuming complete combustion, 12.8 percent oxygen and 5.4 percent carbon dioxide are expected from mass balances.

Downstream Temperature Profiles

Maximum outlet temperature measured at 0.1080 M downstream of the catalyst core was around 1475^{o}K as shown in Figure IV-5 and this outlet temperature corresponds to 94 percent adiabaticity.

Pressure Drop

Plots of isothermal and combustion pressure drops are shown in Figure IV-6. The combustion pressure drop averaged 6,660 N/M^2 during the initial 200 hours of the life test but leveled off around 9,850 N/M^2 for the remainder of the life test.

Isothermal pressure drop at prefuel conditions has the same trend as combustion pressure drop.

Table IV-1

Analyses[1] of #2 Diesel Fuels Used for Catalyst Life Tests

Test	Batch #1[2]	Batch #2[3]	Batch #3[4]
Gravity, API @ 60°F (289°K)	33.8	33.9	34.0
Flash Point, °K	351.0	348.8	333.2
Pour Point, °K	261	258	250
Water and Sediment, Vol. %	0.1	-Nil-	< .05
Ash, Wt. %	-Nil-	Trace	.016
Colour, ASTM	-	L 2.5	-
Distillation Temperature, °K			
Initial	454.3	461.0	440.0
10%	487.6	489.9	483.2
50%	532.1	534.3	531.0
90%	575.4	583.2	577.6
End Point	608.8	613.2	593.2
Recovery, %	99	98	96
Carbon/Hydrogen Atomic Ratio	0.585	0.602	0.529
Heating Value, Joule/Kg (Gross)	4.57×10^7	4.57×10^7	4.55×10^7
Viscosity, SUS at 311°K	34.6	35.0	35.3
Sulfur, Wt%	.08	.11	.13-.14
Nitrogen, ppm	500	< 10	600
Phosphorous, ppm	-	< 1	< 1
Lead, ppm	1	< 1	2.4

[1] Analyses performed by Saybolt and Co.

[2] Batch #1 used between 0 and 206 hours on stream.

[3] Batch #2 used between 206 and 825 hours on stream.

[4] Batch #3 used between 825 and 1065 hours on stream.

Table IV-2

Life Test Conditions

Catalyst Core Dimensions	0.0254 M diameter X 0.1524 M length
Fuel Type	#2 Diesel Oil
Air Flow	1.42×10^{-2} Kg/S
Fuel Flow	3.73×10^{-4} Kg/S
Air/Fuel	38/1 (Kg/Kg)
Inlet Temperature	$633^{o}K$
Adiabatic Flame Temperature	$1533^{o}K$
Inlet Pressure	5×10^{5} N/M^{2}
Reference Velocity	14 M/S
Space Velocity at NTP	142 M^{3}/S - M^{3} Cat

Table IV-3

<u>Properties of Test Catalyst Core</u>

Catalyst Identification	DXE-442
Catalyst Components	Palladium
Support	Zircon Composite
Channel Density	
Nominal	256 Channels/in^2
Actual	144-159 Channels/1" ϕ core
Hydraulic Diameter	9.754×10^{-4} M
Open Fraction	65.5%
Bulk Surface Area	2683 M^2/M^3
Length	.1524 M

4-2. DIESEL PARAMETRIC TESTS

In order to define the low emissions operating ranges for the initial and final catalyst performance after 1000 hours on stream, a series of parametric tests were carried out over the following operating condition range:

Fuel	#2 Diesel Oil
Pressure	1×10^5 and 5×10^5 N/M^2
Air Preheat Temperature	633 and 723^oK
Adiabatic Flame Temperature	1366, 1450 and 1533^oK
Reference Velocity	14 and 26 M/S

Table IV-4 gives initial and final parametric test results for the comparison runs, and detailed results are summarized in Appendices C and D respectively.

The performance of the test catalyst core has significantly declined after 1000 hours on stream, particularly at low adiabatic flame temperatures. Comparison plots showing effects of inlet temperature, reference velocity and pressure on combustion efficiency, are presented in Figures IV-8, 9, and 10, for the initial (after 63 hours on stream) and final (after 1014 hours on stream) parametric tests over the range of adiabatic flame temperature used.

Table IV-4

Diesel Parametric Test Results

Run Number	Pressure (Atm)	Air Preheat Temperature (°C)	Adiabatic Flame Temperature (°C)	Fuel/Air Ratio (W./W.)	Reference Velocity (M/Sec)	Emissions + CO (ppm)	UHC (ppm)	NO_x (ppm)	Combustion Efficiency (%) Initial	Final
146-1	5	360	1093	0.0210	14	345 >5000	0 -	3.6 -	99.20	64.6 *
146-2	5	360	1176	0.0236	14	35 3300	5 310	3.5 5.4	99.90	91.58
146-3	5	450	1093	0.0188	14	300 >5000	4 -	3.2 -	99.21	73.1 *
146-4	5	450	1176	0.0213	14	25 2200	0 145	3.7 4.1	99.94	94.19
146-5	5	450	1260	0.0241	14	15 93	0 0	4.3 5.1	99.97	99.82
146-6	5	360	1093	0.0210	26	> 5000 >5000	- -	- -	49.1*	25.5 *
146-7	5	360	1176	0.0236	26	5000 >5000	900 -	4.0 -	84.87	25.4 *
146-8	5	360	1280	0.0270	26	500 1400	0 45	2.8 4.7	99.12	97.33
146-9	1	360	1093	0.0210	22	> 5000 >5000	- -	- -	36.8*	26.2 *
146-10	1	360	1176	0.0236	22	> 5000 >5000	- -	- -	61.3*	23.2 *
146-11	1	360	1280	0.0270	22	700 2800	11 200	5.2 5.3	98.70	94.08
146-12	5	360	1093	0.0210	14	263 >5000	3 -	4.0 -	99.38	32.0 *
146-13	5	360	1176	0.0236	14	30 2900	0 210	3.5 5.8	99.94	92.97

* Estimate based on % Adiabaticity = (Measured temperature rise/Theoretical temperature rise)

\+ Large type denotes emissions at end of life test.
Small type denotes emissions at beginning of life test.

Figure IV-8 Effect of Air Preheat Temperature on Combustion Efficiency Before and After Life Testing

Test Conditions

Run No. 146-1 through 5

Fuel	:	#2 Diesel
Reference Velocity	:	14 M/S
Inlet Pressure	:	5×10^5 N/M^2
Air Preheat Temperature	△ :	633^{o}K
	⊙ :	723^{o}K

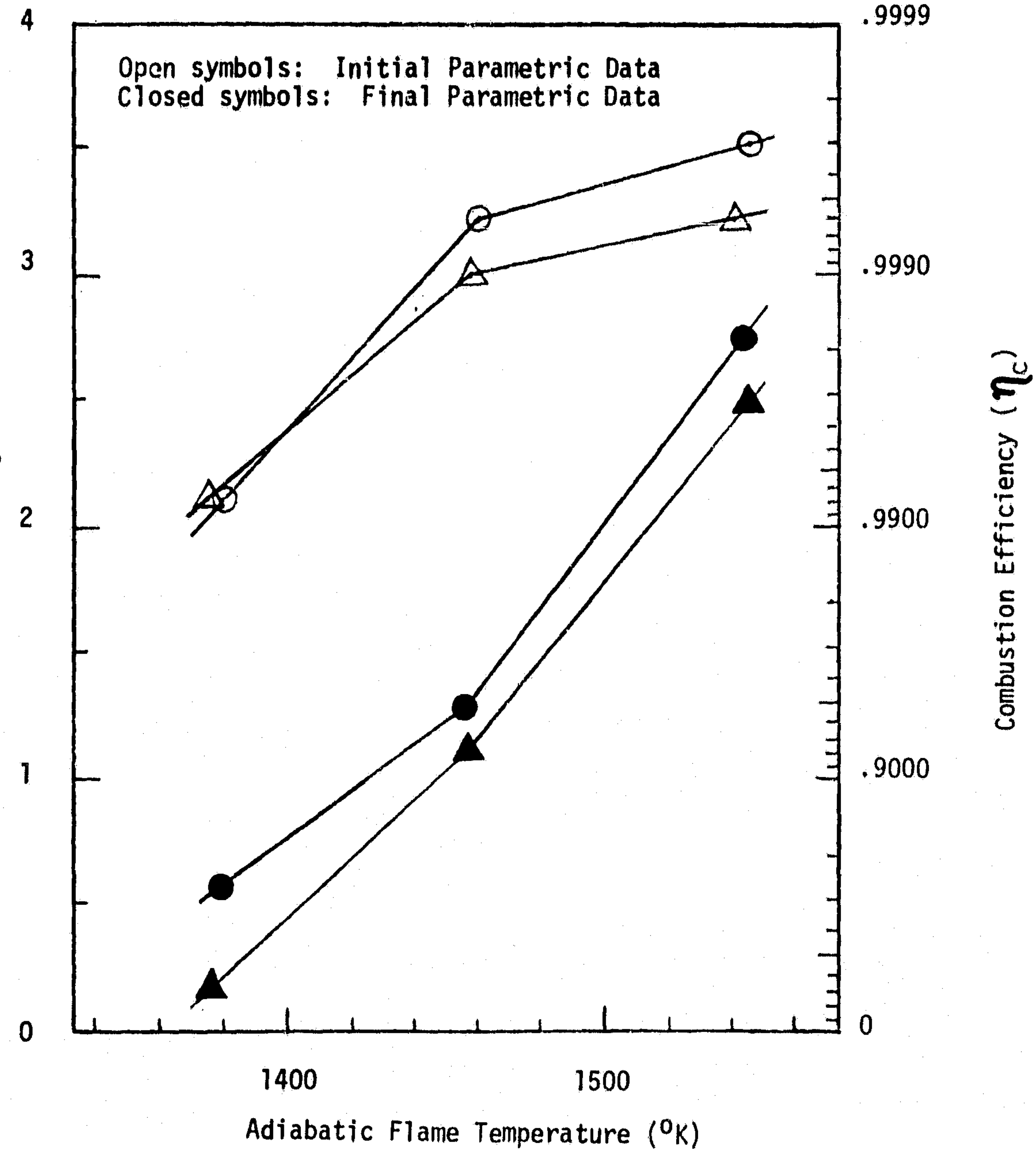


Figure IV-9 Effect of Reference Velocity on Combustion Efficiency Before and After Life Testing

Test Conditions

Run No. 146-1,2,6,7 and 8
Fuel : #2 Diesel
Inlet Pressure : 5 X 10^5 N/M^2
Air Preheat Temp. : 633°K
Reference Velocity △ : 14 M/S
⊙ : 26 M/S
Open Symbols: Initial Parametric Data
Closed Symbols: Final Parametric Data

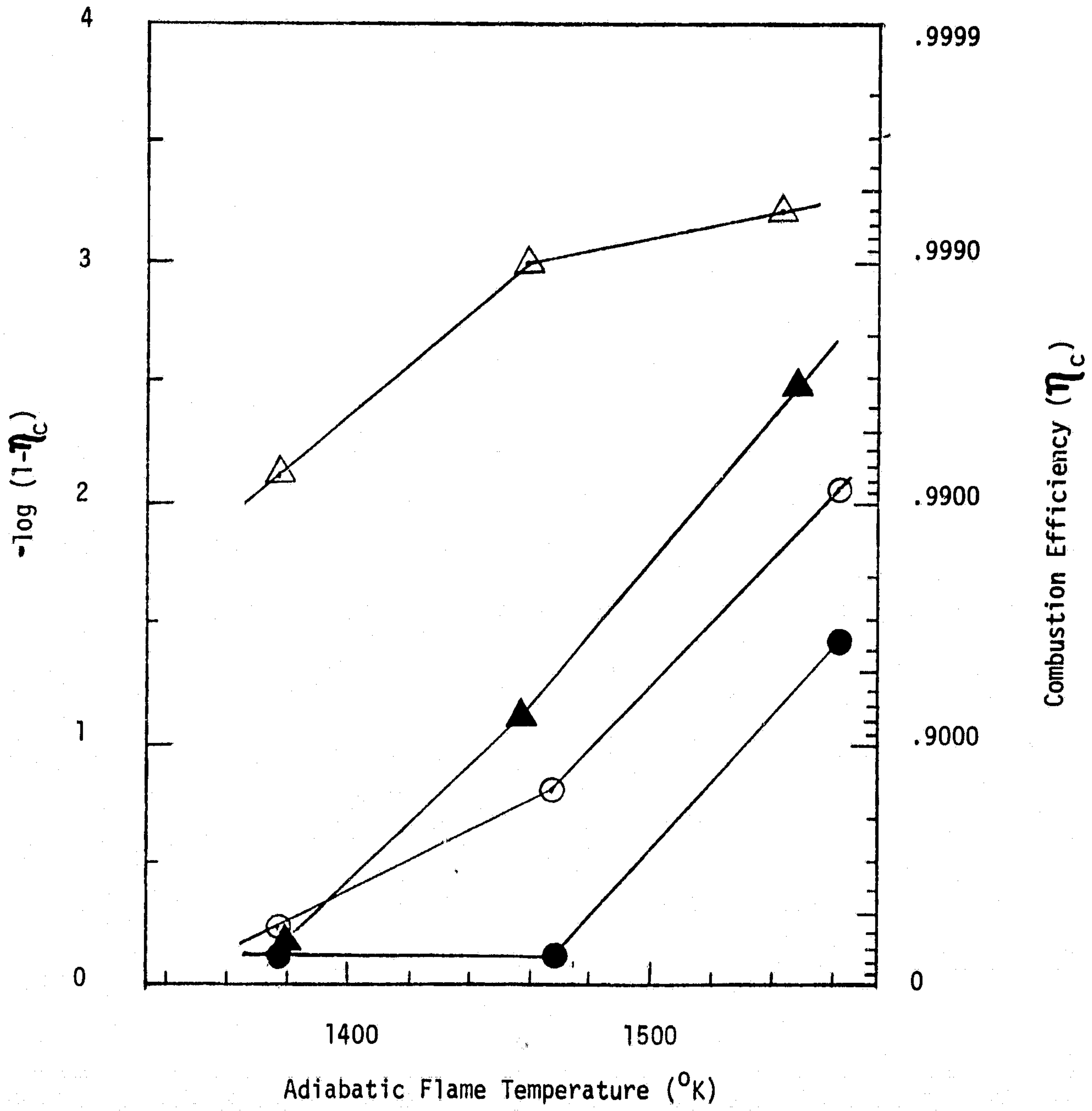
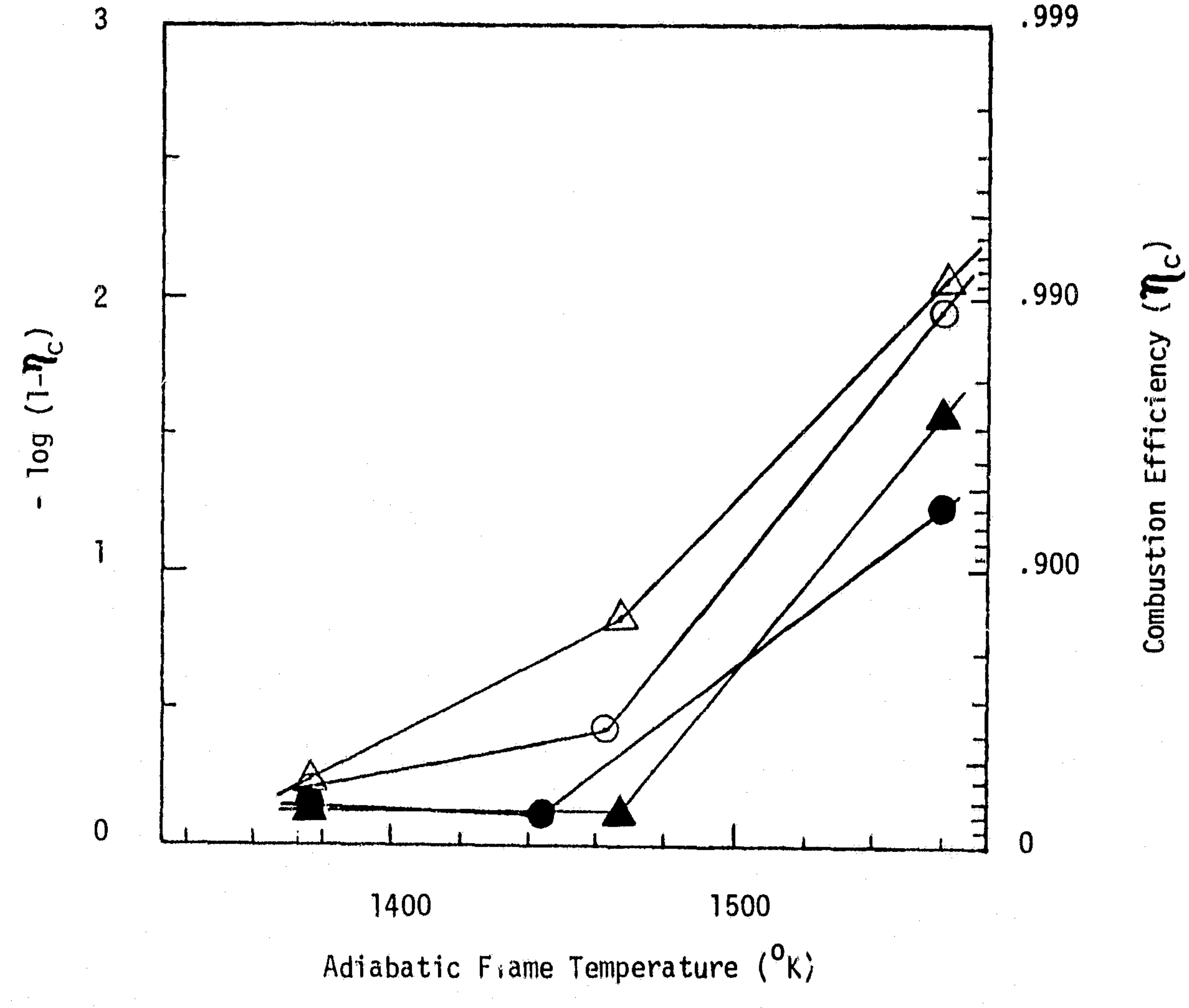


Figure IV-10 Effect of Pressure on Combustion Efficiency

Before and After Life Testing

Test Conditions

Run No. 146-6 through 11
Fuel : #2 Diesel
Reference Velocity : 22-26 M/S
Air Preheat Temperature : 633 ^{o}K
Inlet Pressure ⊙ : 1 X 10^5 N/M^2
△ : 5 X 10^5 N/M^2
Open Symbols: Initial Parametric Data
Closed Symbols: Final Parametric Data



4-3. CARBON MONOXIDE ACTIVITY TEST

Carbon monoxide activity tests were performed periodically at 24 hours, 206 hours, 507 hours, 729 hours and 1014 hours on stream during life testing. Carbon monoxide conversion was measured under test conditions listed in Table IV-5. The test procedures are summarized as follows:

1. Set air flow to 10.55×10^{-3} Kg/s at 1×10^{5} N/M^{2} pressure.

2. Set the air preheat temperature to 453°K.

3. Introduce C.P. carbon monoxide at 4000 ppm into the feed stream.

4. If ignition occurs, measure temperature rise and CO conversion; if no ignition, increase air preheat in 20°K increments until ignition occurs. (When increasing temperature, CO fuel is off.)

5. After ignition occurs, proceed in 40°K increments in air preheat temperature and measure temperature rise and CO conversion, again using a CO concentration of 4000 ppm in the feed.

6. Stop test when air preheat temperature reaches 673-723°K.

Table IV-6 gives test results obtained from each CO activity test. CO conversion data are plotted versus air preheat temperature in Figure IV-11.

Activity Test Procedure Modification

Since poor results of the previous standard CO activity test were obtained at 729 hours on stream, a different approach was tried to obtain mass transfer limited CO conversion levels by starting the test from a high temperature (turndown) and with CO fuel on continuously.

High CO conversion data denoted by closed symbols in Figure IV-12 were obtained with fuel on continuously and mass transfer limited CO conversions of approximately 40 percent were achieved. Standard CO activity test results are shown in Figure IV-12 for comparison.

4.4 PRESSURE DROP

In addition to pressu drop measurements made during life testing and diesel parametric runs, isothermal pressure drop data was taken at various times during the life test and these results are tabulated in Appendix E.

Figure IV-11

Carbon Monoxide Activity Test Response
During Life Test of Catalyst Core DXE-442

Legend

- ⊡ 24 Hours Aging
- ⊙ 206 Hours Aging
- △ 507 Hours Aging
- ⊙ 729 Hours Aging
- ▽ 1014 Hours Aging

Run Conditions

Reference Velocity = 36.5 M/S (at 633°K)
Feed CO = 4000 Vppm
Pressure = 1 X 10^5 N/M^2
Catalyst Core
Dimensions = .0254M ϕ X .1524M L

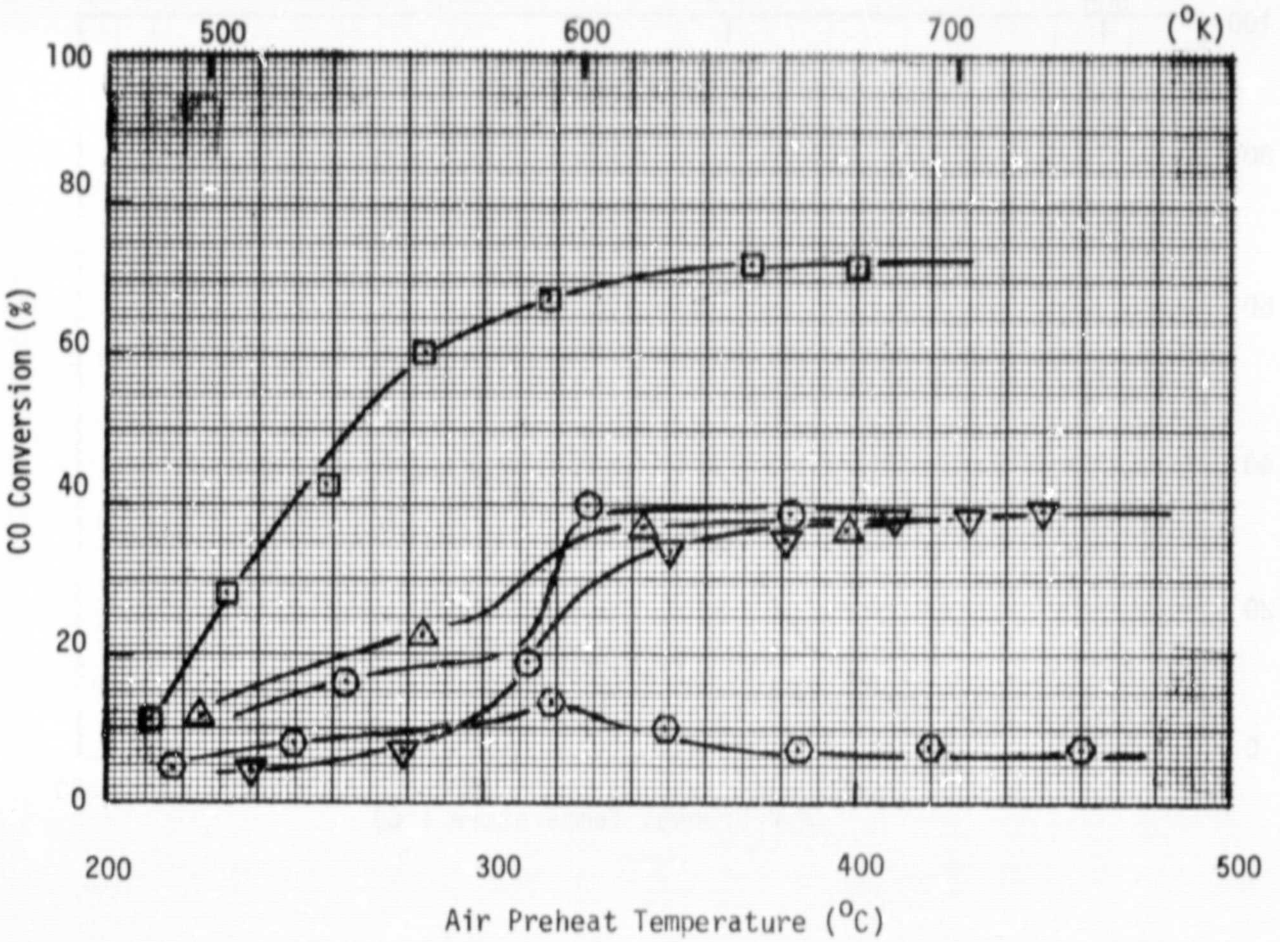


Figure IV-12

Carbon Monoxide Activity Responses

After 1014 Hours Using Catalyst Core DXE-442

Run Conditions

Reference Velocity = 36.5 M/S (at 633°K)
Feed CO = 4000 Vppm
Pressure = 1 X 10^5 N/M^2
Catalyst Core
Dimensions = 0.254M ø X .1524M L

Legend

▽ 1014 Hours Aging (Standard procedure; temperature incrementally increased)

▼ 1014 Hours Aging (Modified procedure; temperature incrementally decreased)

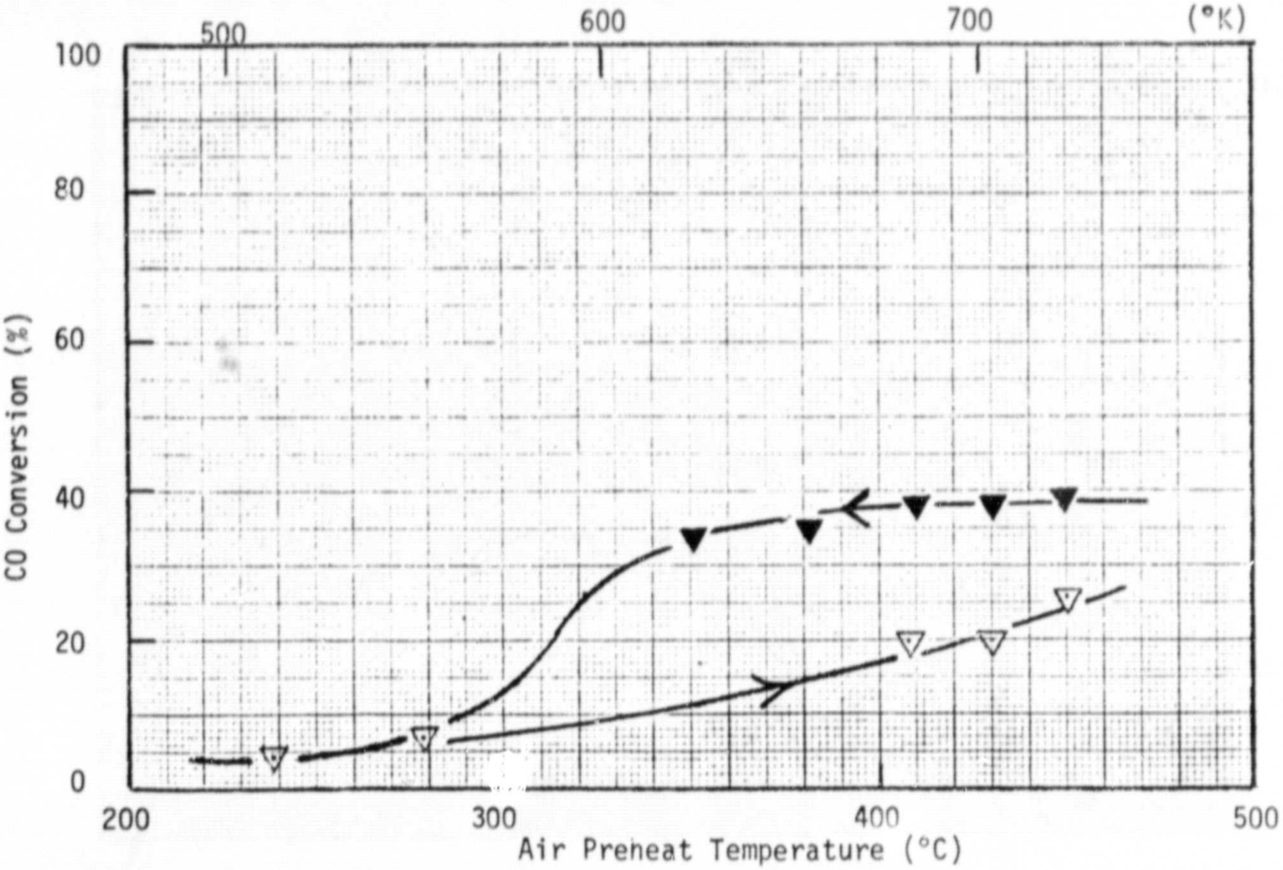


Table IV-5

Carbon Monoxide Activity Test Conditions

Fuel Type	C.P. Grade CO
Air Flow	10.55×10^{-3} Kg/S
Fuel Flow	4.09×10^{-5} Kg/S
Air/Fuel	258/1 Kg/Kg
Inlet Temperature	Varied up to $733^{o}K$
Inlet Pressure	1×10^{5} N/M^2
Reference Velocity at $633^{o}K$	36 M/S
Space Velocity at NTP	125 $M^3/S-M^3$ Cat.

Table IV-6

CO Activity Test Results

Test Conditions

Reference Velocity (at 633°K)	:	36 M/S
Feed CO	:	400[illegible] [illegible]pm
Pressure	:	1.4×10^5 N/M^2
Catalyst Core Size	:	.0254 M X .1524 M L

I. After 24 Hours Aging

Inlet Temperature (°K)	CO In Effluent (Vppm)	CO Conversion (%)
485	3580	10.5
501	2900	27.5
525	2290	42.8
558	1560	61.0
599	1280	68.0
645	1100	72.5
677	1100	72.5

II. After 206 Hours Aging

546	3380	15.5
592	3220	19.5
603	2400 (4120 Feed)	41.7
658	2430	39.3

Table IV-6

CO Activity Test Results (Cont'd)

III. After 507 Hours Aging

498	3520	12.0
558	3080	23.0
618	2500	37.5
671	2480	38.0

IV. After 729 Hours Aging

493	3840	4.0
523	3700	7.5
593	3460	13.5
623	3600	10.0
658	3700	7.5
693	3700	7.5
733	3700	7.5

V. After 1014 Hours Aging

513	3820	4.5
552	3720	7.0
681	3200	20.0
703	3200	20.0
723	2960	26.0
623	2620	34.5 *
653	2580	35.5 *
693	2420	39.5 *
713	2410	39.8 *
733	2405	39.8 *

* (From high temperature start-up with CO on continuously and temperature turndown)

V. DISCUSSION OF TEST RESULTS

The primary criteria for evaluation of catalyst performance consisted of experimentally determining if the range of low emissions operation and physical durability of the catalyst core could be maintained after 1000 hours of aging with #2 diesel fuel at 5 atmospheres pressure. Secondary criteria considered were the maintenance of carbon monoxide activity and range of low emissions performance in diesel parametric tests before and after 1000 hours aging at 5 atmospheres pressure.

5-1. LIFE TEST RESULTS

a) Emissions Performance

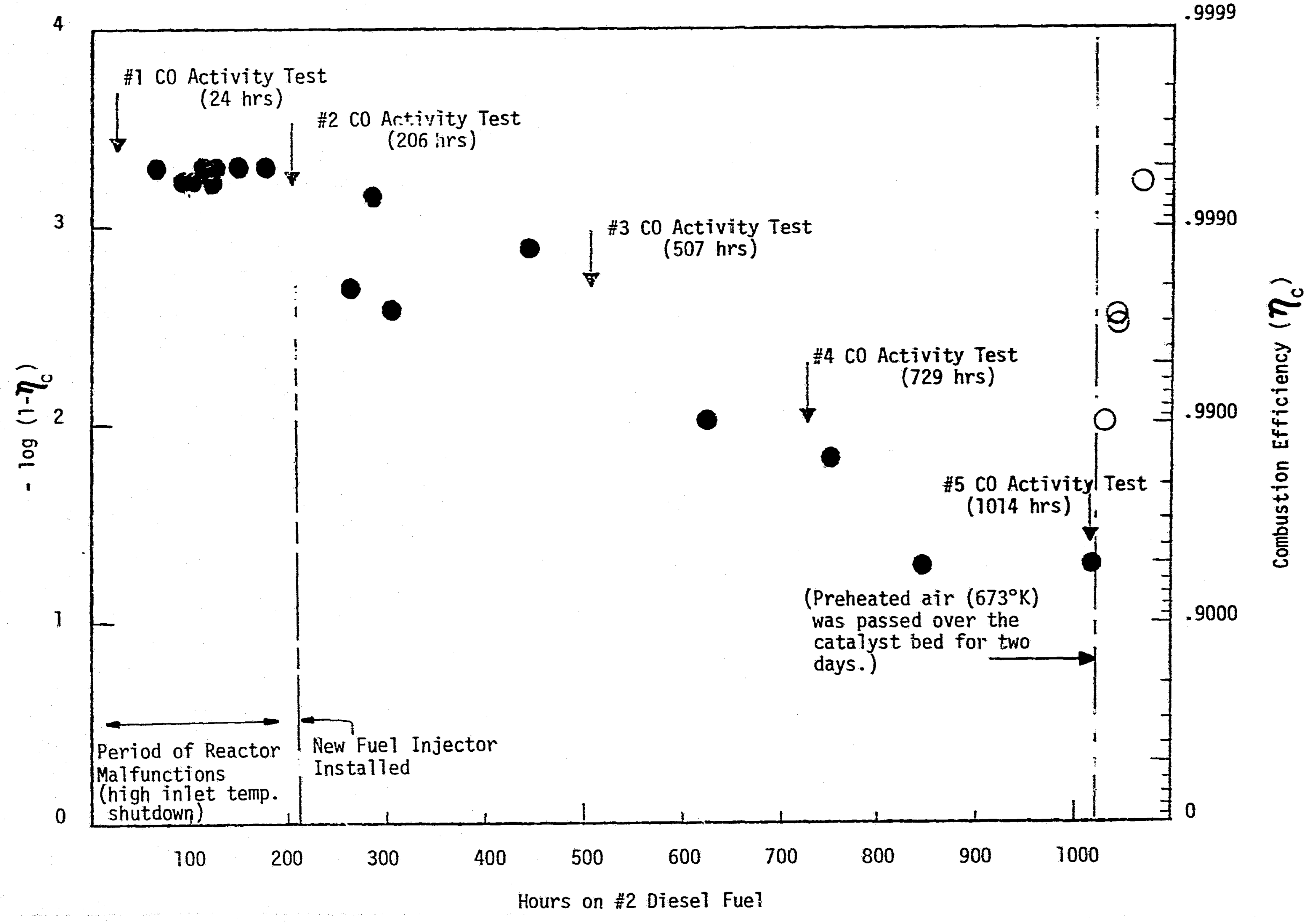
During the 1000 hour durability life test of the catalyst core, DXE-442, at 5 atmospheres pressure, emissions were as follows:

Emissions Measured		Initial after after 63 hours	After 1014 hours	After 1062 hours
UHC (as C_3)	:	0	146	0
CO	:	35	2420	35
NO_x	:	5.7	5.6	4.3

Combustion efficiencies were calculated from carbon balance[1] in the exhaust gas stream and plotted in Figure V-1.

A high combustion efficiency was maintained around 99.95% during the initial 200 hours of the life test and a gradual degradation in the catalyst performance was noted for the remainder of the life test. Combustion efficiency dropped to 95 percent at 848 and 1014 hours on stream. There is no evidence for abnormal contaminants in #2 diesel fuel which had been used during the particular period. The fuel analysis of Table IV-1 indicates that batch #3 fuel contains higher sulfur and lead than the previous batches but is comparable with the fuel used during the 1000 hour life test at one atmosphere(1). Final emissions levels obtained after 1062 hours on stream suggest that some sort of reversible catalyst deactivation may have occurred during the life test.

Figure V-1 Response of Combustion Efficiency During Five Atmospheres Life Testing



Compared to the one atmosphere life test results discussed in Section 5-6, the deactivation of the catalyst was more severe at 5 atmospheres pressure. The test catalyst was subject to five times the total mass throughput, thus any decline in catalyst performance caused by poison contaminants in the fuel or by attrition of active catalytic components would have been accelerated.

At the end of the life test, catalyst performance was partially restored by passing preheated air in-situ over the catalyst at 673°K for a two day period. Thereafter, high combustion efficiencies were observed as shown in Table V-1. This unexpected result may have caused catalyst regeneration by: 1) removal of fuel deposited poisons from the catalyst surface, or 2) alteration of the active catalyst surface by some other mechanism.

NO_X emissions were fairly stable and ranged from 4-5 ppm by volume. Oxides of nitrogen are generated entirely from fuel bound nitrogen (see Table IV-1). Significant thermal NO_X generation is unlikely at the operating temperatures used in a well mixed CATCOM* system.

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* Engelhard tradename

Table V-1

Comparison of Performance Data at Start and End of Life Test

	Start	End	Results After Final CO Activity Tests at 1062 Hours
Hours on Diesel Fuel	63	1014	1062
Air Flow Rate (Kg/sec)	1.43 X 10^{-2}	1.43 X 10^{-2}	1.43 X 10^{-2}
Fuel/Air Ratio (by weight)	.02647	.02686	.02647
Temperature (^{o}K)			
Preheat Air	633	633	633
Reactor Outlet	1463	1463	1473
Adiabatic Flame	1539	1539	1539
Pressure			
Inlet (N/M^2)	$5.1 * 10^5$	$5.0 * 10^5$	$5.0 * 10^5$
Drop (N/M^2)	6767	9473	9812
Loss (%)	1.31	1.86	1.93
Reference Velocity (M/Sec)	14.0	14.2	14.2
Heat Release Rate (Joules/sec, M^3, N/M^2)	1136	1111	1151
Combustion Efficiency (%)	99.95	94.97	99.94
+Emissions (Vppm)			
CO	30	2420	35
UHC (as C_3)	0	146	0
NO_x	5.7	5.0	4.3

Catalyst Core Dimension, Nominal 0.0254 M (Diameter)

* 0.1524M (Long)

+ All emissions measured with water cooled sample probe located at 0.102 M downstream of catalyst core.

b) Physical Durability of DXE-442 Catalyst

Photographs of the inlet and outlet ends of the test catalyst used for life testing are presented in Figure V-2a. Physical damage was limited to minor breakage from catalyst handling during removal of the catalyst substrate and reloading it into the test reactor.

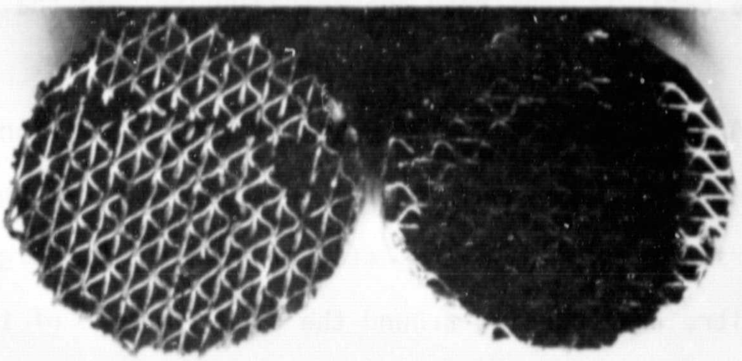
A photograph of the catalyst test configuration is shown in Figure V-2b. As shown, the two test segments are separated by 1/4" spacers and secured in the catalyst holder using high temperature cement and Fibre Frax packing around the circumference of the substrates.

Physical and chemical analysis of the catalyst cores used for the 1000 hour durability test will be carried out after approval by NASA personnel.

INLET ENDS

UPSTREAM
S/N 4070 J-12
DXE-442

DOWNSTREAM
S/N 4070 J-1
DXE-442



OUTLET ENDS

UPSTREAM
S/N 4070 J-12
DXE-442

DOWNSTREAM
S/N 4070 J-1
DXE-442

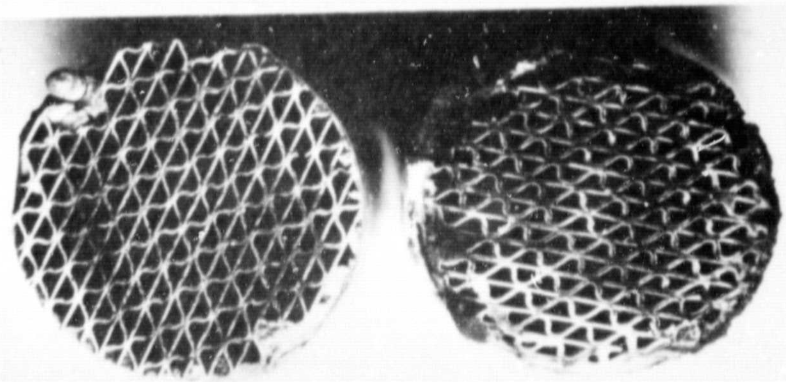


Figure V-2a Photographs of Catalyst Core DXE-442 After 1000 Hours Life Testing

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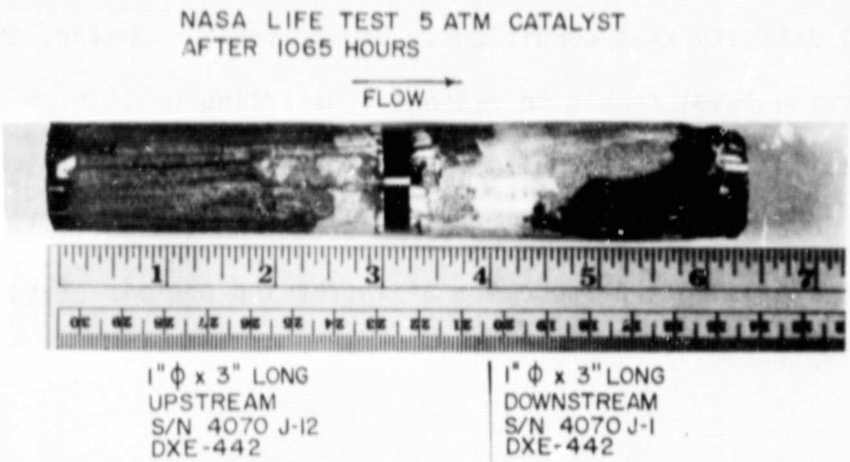


Figure V-2b Photographs of Catalyst Core DXE-442
After 1000 Hours Life Testing

5.2 CARBON MONOXIDE ACTIVITY TESTING

The CO activity test is intended to detect differences in effective catalytic surface area by measuring mass transfer limited CO conversion levels at high flow conditions. Stabilized CO conversion of approximately 40% were obtained at 206 and 507 hours on stream.

From the data taken after 729 and 1014 hours on stream, it was apparent that these conversion levels could not be achieved under normal activity test conditions. It was found, however, that 40% CO conversion levels could be reached by starting up at high temperature and leaving feed CO on while decreasing the air preheat temperature. Lower CO conversion levels were measured when the activity test was done by the standard procedure of increasing the air preheat temperature as illustrated in Figure IV-12.

The observed hysteresis phenomenon has been well described for heterogeneous reaction systems for CO oxidation over various metal component catalysts[8]. Although mass transfer limited conversions in the range of 40% could be achieved after 1000 hours on stream, it is apparent that more severe catalyst deactivation had occurred during the 5 atmosphere life test than observed in any 1 atmosphere life test conducted to date, including that carried out using a similar DXE-442 catalyst preparation.

5.3 DIESEL PARAMETRICS

Effect of Air Preheat Temperature Before and After Life Testing

Effect of air preheat temperature on combustion efficiency is shown in Figure IV-8, a plot of the negative logarithm of complement combustion efficiency versus adiabatic flame temperature at 633°K and 723°K air preheat temperatures.

Since combustion efficiency obtained with the initial catalyst core was not sensitive to inlet temperature at a low adiabatic flame temperature (Run No. 146-1 (12) and 3), there was no apparent kinetic activity limitation in the overall reaction. Above an adiabatic flame temperature of 1450°K, combustion efficiency was not affected by adiabatic flame temperature (Run No. 146-2 (13), 4 and 5) due to the highly active catalytic combustion.

However, the performance of the catalyst had changed after 1014 hours on stream as shown in Figure IV-8. A kinetic effect was noted at low adiabatic flame temperatures and the catalytically supported homogeneous combustion zone was reduced at high adiabatic flame temperatures. This was attributed to partial deactivation. Thus, combustion efficiency is more sensitive to adiabatic flame temperature after 1014 hours on stream, and higher fuel/air ratios are required to maintain efficient, low emissions performance. After 1014 hours on stream, a minimum adiabatic flame temperature to obtain combustion efficiency greater than 99 percent is interpolated to be 1513°K from Figure IV-8 at 633°K air preheat temperature and 14 M/S reference velocity.

Effect of Reference Velocity Before and After Life Testing

Combustion efficiency is a strong function of reference velocity as shown in Figure IV-9, a plot of the negative logarithm of complement combustion efficiency versus adiabatic flame temperature at 14 M/S and 26 M/S reference velocities. Combustion efficiency substantially declined as reference velocity was increased up to 26 M/S for both the initial and final catalyst performance.

Initial combustion efficiencies greater than 99 percent were achieved over the entire range of adiabatic flame temperatures at 14 M/S reference velocity. An adiabatic flame temperature of 1553°K was required to obtain combustion efficiencies greater than 99 percent at 26 M/S reference velocity (Run No. 146-8).

After 1014 hours on stream, an adiabatic flame temperature required for 99 percent combustion efficiency is extrapolated to be 1597°K at 26 M/S reference velocity from Figure IV-9.

Effect of Pressure Before and After Life Testing

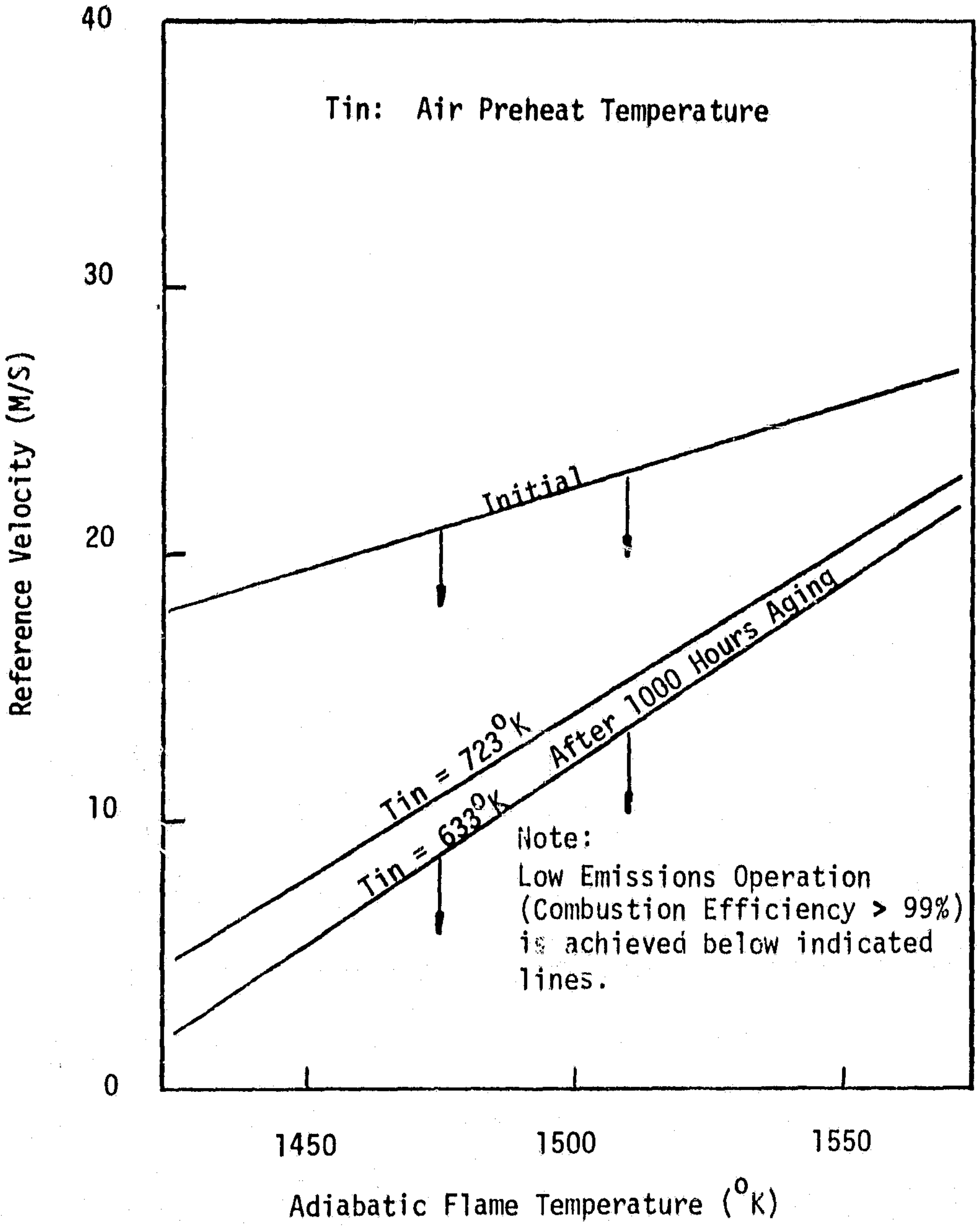
As shown in Figure IV-10, a plot of the negative logarithm of complement combustion efficiency versus adiabatic flame temperature, at 1×10^5 N/M^2 and 5×10^5 N/M^2 pressures, shows that pressure is the least sensitive variable, although slightly higher combustion efficiencies were obtained at 5×10^5 N/M^2 pressure and the higher adiabatic flame temperatures. The same trend was observed at the beginning and after 1014 hours on stream.

5.4 LOW EMISSIONS OPERATING CONDITION RANGE

The low emissions operating regions have been defined as those with combustion efficiency performance greater than 99 percent as shown in Figure V-3. The boundary for the required adiabatic flame temperature was formulated for a high combustion efficiency at a given reference velocity by interpolating parametric test results assuming a linear relationship between each data point in the plot of logarithm of complement combustion efficiency versus adiabatic flame temperature (shown in Figures IV-8 and 9).

As illustrated in Figure V-3, the region of low emissions operation has been narrowed after life testing at 5 atmospheres pressure. Inlet temperature in the range of 633°K to 723°K does not affect the initial boundary but is significant after 1014 hours on stream.

Figure V-3 Low Emissions Operating Condition Range



5.5 PRESSURE DROP

The pressure loss data obtained from the life and parametric tests were analyzed and models were derived for both isothermal and combustion pressure losses.

Isothermal/Combustion Pressure Losses

Combustion to isothermal pressure loss ratios from parametric test results are shown in Figure V-4. Combustion to isothermal pressure loss ratios from experimental life test results are plotted in Figure V-5.

Figure V-4 Plot of Combustion to Isothermal Pressure Loss Ratio Versus Dimensionless Temperature Rise

Run Conditions

Fuel	: #2 Diesel
Reference Velocity	: 14 - 26 M/S
Air Pressure Temperature	: 633 - 723 ^{o}K
Inlet Pressure	: 1 X 10^5 - 5 X 10^5 N/M^2
Fuel to Air Ratio (by Wt.)	: .0201 - .0270

Data From Final Parametric Test Results (Appendix D)

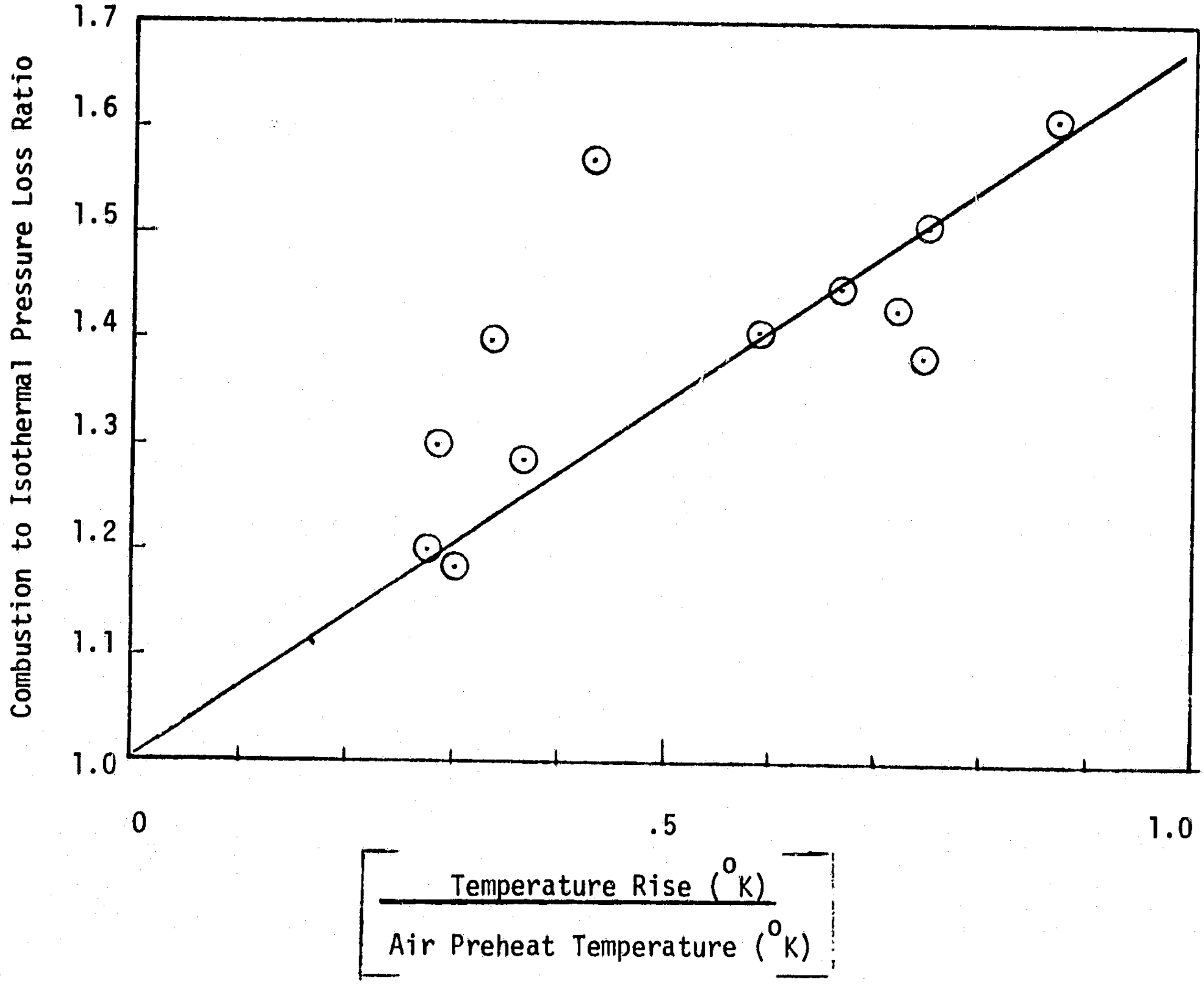
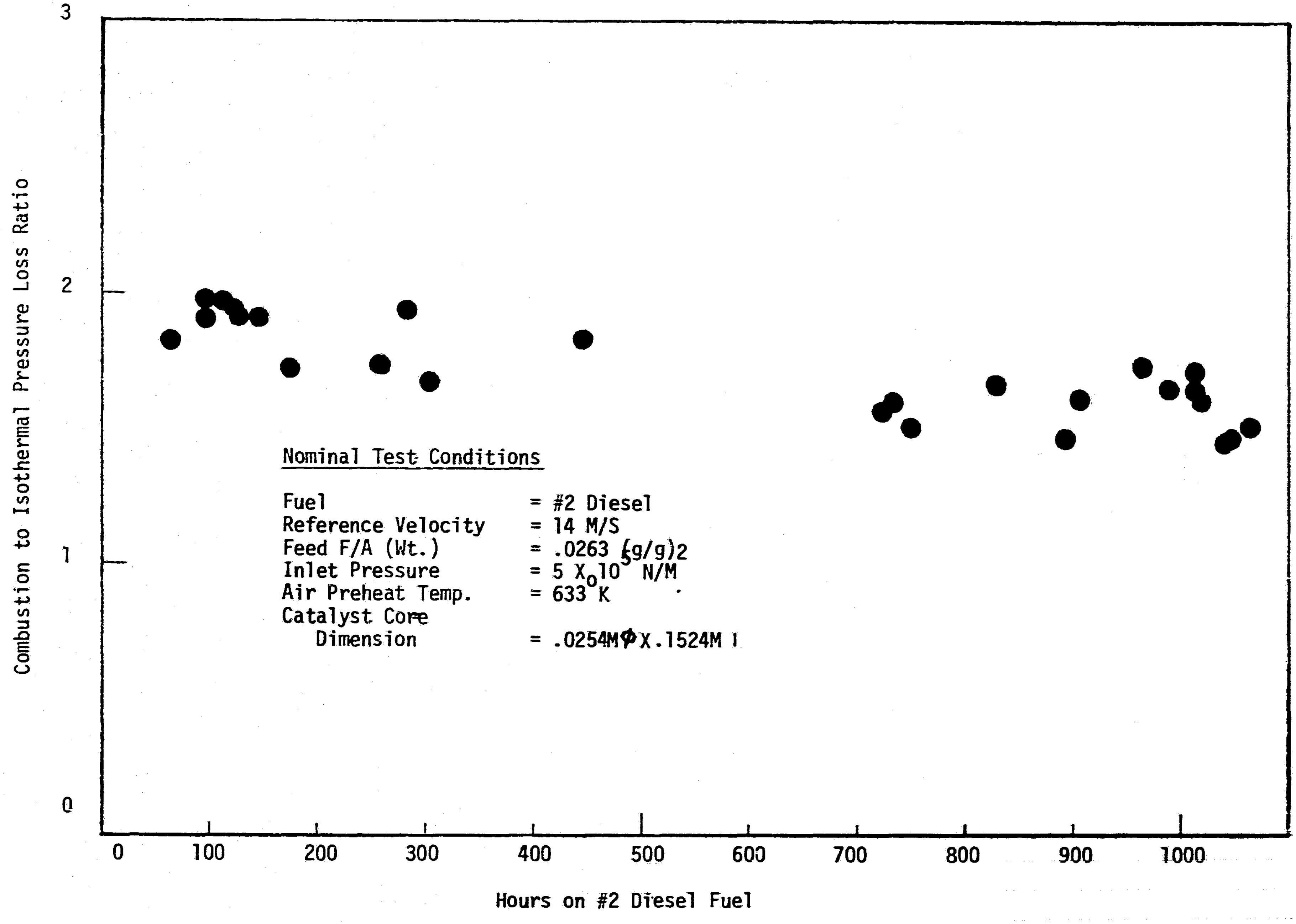


Figure V-5 Response of Combustion to Isothermal Pressure Loss Ratio

During Five Atmosphere Life Testing



5.6 COMPARISONS OF CATALYST PERFORMANCE AT ONE AND FIVE ATMOSPHERE LIFE TEST CONDITIONS FOR CATALYST CORE DXE-442

Life Test Results

Figures V-6 and V-7 show comparisons of hydrocarbon and carbon monoxide emissions respectively during life testing for the same DXE-442 catalyst preparation at one and five atmospheres pressures. Despite the similar initial emissions ($CO \simeq 30$ Vppm and $HC < 3$ Vppm) at both conditions, a significant deactivation was observed at five atmospheres pressure, especially after 500 hours on stream. Average emissions during 1000 hours of life testing for DXE-442 were as follows:

	1 atm	5 atm
Unburned Hydrocarbons (C_3, Vppm)	3.2	4.9
Carbon Monoxide (Vppm)	65	252

Combustion Efficiency (%)	99.86	99.50

The comparative emissions performance of DXE-442 catalyst indicates that the 5 atmosphere life test conditions were more severe than those at 1 atmosphere pressure.

CO Activity Test

The CO activity test results during one atmosphere life testing for the same DXE-442 catalyst used for five atmosphere testing are shown in Figure V-8. As illustrated, the CO activity response did not change throughout the 1000 hour, one atmosphere life test. Stabilized CO conversion levels of 40% or better were consistently attained.

In contrast, the DXE-442 catalyst tested at five atmospheres showed a decline in CO conversion performance after 500 hours on-stream, using standard CO activity test procedures.

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Figure V-6 Comparison of Hydrocarbon Emissions During Life Testing at One and Five Atmospheres Pressures

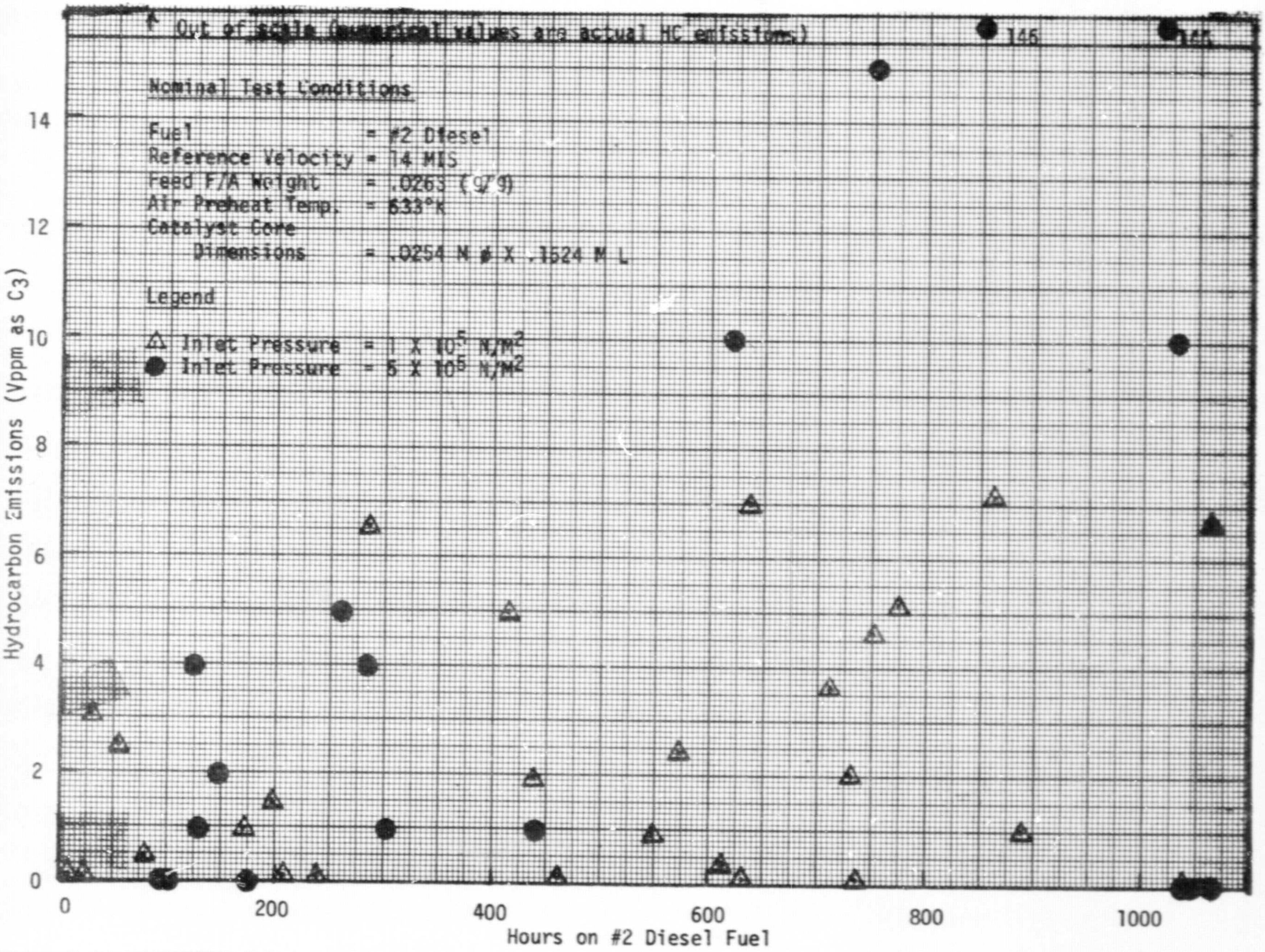

Figure V-7 Comparison of Carbon Monoxide Emissions During Life Testing at One and Five Atmospheres Pressures

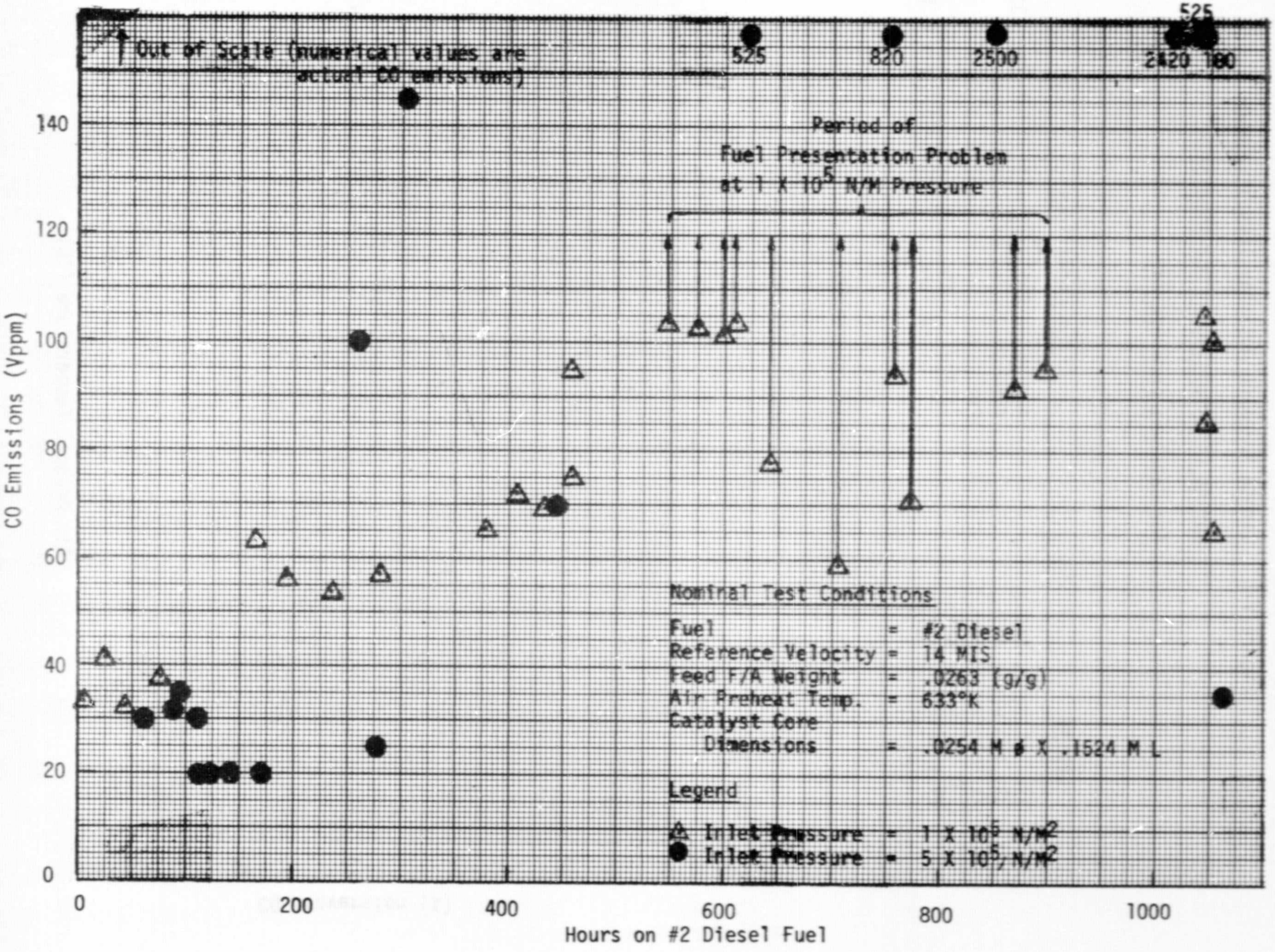

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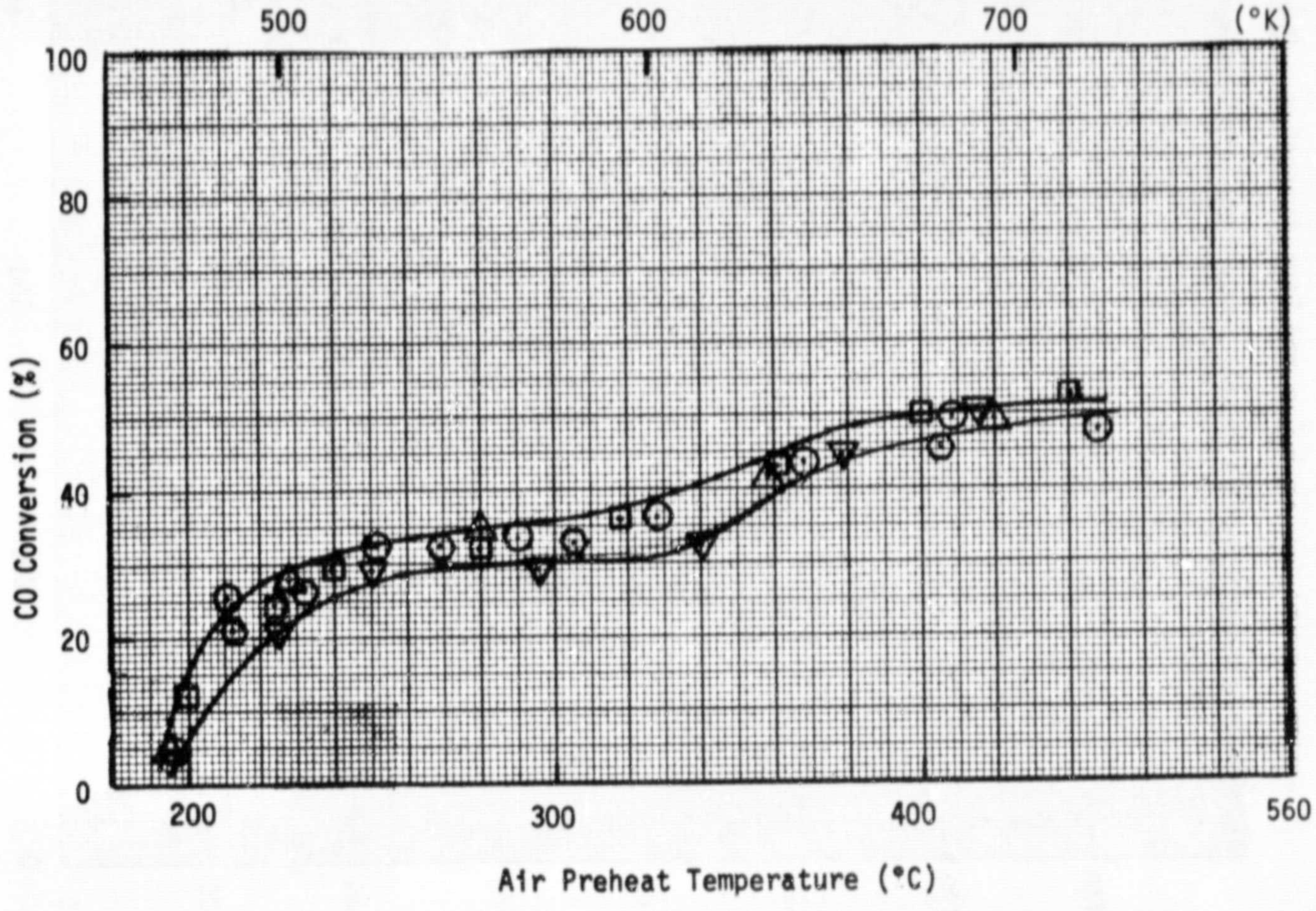
Figure V-8 Carbon Monoxide Activity Test Response During Life Testing at One Atmosphere for Catalyst Core DXE-442

Legend

- □ 26 Hours Aging
- ⊙ 259 Hours Aging
- △ 470 Hours Aging
- ⬡ 748 Hours Aging
- ▽ 1012 Hours Aging

Run Conditions

Reference Velocity = 36.5 M/S (at 633°K)
Feed CO = 4000 Vppm
Pressure = 1×10^5 N/M^2
Catalyst Core Dimensions = 0.0254 M ø x 0.1524 M L



VI. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions have been made from the experimental test results obtained under this contract:

1. The catalyst core tested, DXE-442, for 1000 hours of continuous operation at 5-atmospheres with #2 diesel fuel exhibited the following emissions:

	Initial	After 1014 hours	After 1062 hours
Unburned Hydrocarbons (C_3, Vppm)	0	146	0
Carbon Monoxide (Vppm)	30	2420	35
Nitrogen Oxides (Vppm)	5.7	5.6	4.3

2. The DXE-442 catalyst core tested maintained its physical integrity throughout the 1000-hour, 5-atmospher life test at operating temperatures characteristic of catalytically-supported thermal combustion operating temperatures (1533°K) and withstood the thermal shock of numerous intentional and unintentional startups and shutdowns without any evidence of failure.

3. NO_x emissions measured were consistently low throughout endurance and parametric testing and can be maintained at 4-5 Vppm.

4. The cause of the progressively poorer performance over the duration of the 1000-hour test was at least partially reversible, and the original low-emissions capability was restored after a 48-hour exposure to 773°K air.

5. The modified CO-activity test data indicated that adequate mass transfer surface was retained, but kinetic (ignition, light off) activity had been severely deteriorated. This may have been due to the exposure of the catalyst to high temperatures resulting from preburning early in the tests. However, the exact mechanism for catalyst deactivation has not been conclusively identifed.

6. Although there is confidence that the catalyst core tested could maintain physical integrity well beyond 1000 hours, further endurance testing of this particular catalyst is not recommended because the test results indicate that, under laboratory test conditions after 1000 hours at 5-atmospheres, the DXE-442 catalyst tested has deactivated to the extent that performance has become marginal, particularly in terms of CO emissions.

7. It is recommended that either the test be repeated with a new catalyst using the successfully modified reactor, or carry out further development work to improve the catalyst high temperature capability (1644-1700°K) and to improve catalyst life.

VII. REFERENCES

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APPENDIX A

5 Atmosphere Diesel Fuel Life Test Procedures

a. Set Up Reactor Conditions

(1) Switch on power to the instruments. (Open circuit breaker #4 last on Unit 6.)

(2) Seal off water manometer to avoid overpressuring.

(3) Set air supply pressure to 80 psig.

(4) Set air flowrate on automatic control loop at 1700 scfh (127.5 lb/hr)

(5) Set system pressure to 40 psig using automatic back pressure controller.

(6) Set two air preheat SCR controllers to give 360°C catalyst inlet temperature.

(7) While unit is heating, check safety shutdown system for proper operation systematically following schematic of safety actuations test unit DWG. No. B-602-41-109, Rev. 3 for Unit 6.

(8) Calibrate analytical train according to "Analytical Equipment Procedures".

(9) When inlet temperature is lined out within ±5°C of 360°C, take a set of prefuel readings.

(10) Make sure the automatic level control on the exhaust gas vent cooler system is turned on and functioning properly.

b. Fuel Presentation

(1) Set liquid fuel pump to give an 1840-1860 cc/hr flowrate of #2 diesel fuel (SPG 0.841). This is done by timing the liquid volumetric displacement in a buret with the reactor inlet valve closed and the bypass valve open. Air/fuel ratio desired is 38/1.

(2) Check bypass lines for air bubbles and make sure they are not present before introducing fuel to the reactor.

(3) Fuel flow is equalized by a back pressure regulator set above the final reactor operating pressure (>65 psig).

(4) Using fuel automatic control loop calibration curve, select a fuel flow setting which will give 75% of the final diesel rate (i.e. 0.75 x 1850 = 1387.5 cc/hr).

(5) Introduce fuel to the reactor by opening the reactor inlet valve and then closing the bypass valve (as nearly simultaneously as possible).

(6) Gradually bring fuel and pressure up to life test conditions (fuel: 1850 cc/hr, pressure: 58.8 psig).

(7) Never start up the fuel pump with the reactor inlet valve open or the bypass valve closed.

(8) Never lower pressure rapidly because this can result in a temporarily high fuel flow.

(9) Fuel flow should be checked daily using the buret system at the fuel pumps or bypassing the reactor temporarily and using the liquid fuel buret at the unit.

<u>Overnight and Weekend Operation</u>

a. <u>Setting Up Unattended Operating Conditions</u>

(1) Make sure exhaust vent fan is on for Unit 6.

(2) Shut off the audible alarm.

(3) Pull the water-cooled sample probe out of the reactor and shut off the water pump and close the probe water supply valve. Put a N_2 purge on sample probe to keep it clean.

(4) <u>Carefully</u> set the safety actuation system for the particular reactor in use according to the settings listed on the instrument panel.

APPENDIX B

ENGELHARD INDUSTRIES

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Appendix B: Computer Data Reduction of the Five Atmosphere Life Test Results

RUN IDENTITION: 5 ATMOSPHERE LIFE TEST FOR ENGELHARD CATALYST CORE DXE-442 - BAO - 5/30/79
LOGBOOK: UNIT # 6 BOOK 25 PP. 6-37 FUEL TYPE: #2 DIESEL FUEL

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	EQUIVALENT DIA. IN	HYDRAULIC DIA. IN	PERCENT OPEN AREA %	SPACING IN
1	DXE - 442	4070 J12	1.0 BY 3.0	0.85	0.03840	65.5	******
2	DXE - 442	4070 J1	1.0 BY 3.0	0.89	0.03840	65.5	0.25

	RUN NO.	HOURS ON FUEL	FUEL/AIR RATIO	INLET P ATM	PRESSURE DROP %	INLET T C	OUTLET T C	MAX. T C	MAX. T LOCATION INCHES	REF. VELOCITY INLET FACE M/SEC
1	146-14A	62.8	.0264670	5.0816	1.3145	360.0	1030.0	1190.0	2.250	13.999
2	146-14B	92.0	.0270603	5.0000	1.4027	360.0	1140.0	1225.0	2.250	14.228
3	146-14C	98.7	.0268131	4.9932	1.3712	360.0	1168.0	1202.0	2.250	14.247
4	146-14D	111.6	.0268131	5.0000	1.3693	360.0	1197.0	1220.0	2.250	14.228
5	146-14E	120.8	.0268131	4.9660	1.4124	360.0	1175.0	1206.0	2.250	14.325
6	146-14F	125.7	.0268131	5.0136	1.3323	360.0	1040.0	1190.0	4.250	14.189
7	146-14G	144.8	.0268131	5.0136	1.2657	360.0	1050.0	1195.0	4.250	14.189
8	146-14H	174.0	.0268131	4.9796	1.2073	360.0	1100.0	1200.0	4.250	14.286
9	146-14I	259.8	.0264670	5.0816	1.9717	360.0	825.0	1220.0	4.250	13.999
10	146-14J	281.8	.0264670	5.0952	2.1959	360.0	900.0	1200.0	4.250	13.962
11	146-14K	302.6	.0271921	5.0816	2.0046	360.0	837.0	1202.0	4.250	13.999
12	146-14L	443.4	.0271921	5.0136	2.2649	360.0	850.0	1179.0	4.250	14.189
13	146-14M	620.9	.0271921	5.0136	2.1983	360.0	1083.0	1208.0	4.250	14.189
14	146-14P	749.1	.0270273	5.0136	1.7320	360.0	1112.0	1221.0	4.250	14.189
15	146-14Q	848.4	.0268461	5.0816	1.7746	360.0	1018.0	1188.0	4.250	13.999
16	146-14R	1014.5	.0268625	5.0136	1.8652	360.0	994.0	1190.0	4.250	14.189
17	146-14S	1029.0	.0271921	5.0136	1.9985	360.0	985.0	1170.0	4.250	14.189
18	146-14T	1040.2	.0264670	4.9320	1.8961	360.0	928.0	1172.0	4.250	14.424
19	146-14U	1042.9	.0264670	4.9660	1.8831	360.0	910.0	1170.0	4.250	14.325
20	146-14V	1062.4	.0264670	5.0136	1.9319	360.0	1058.0	1200.0	4.250	14.189

Appendix B (Continued)

RUN IDENTIFICATION: 5 ATMOSPHERE LIFE TEST FOR ENGELHARD CATALYST CORE DXE-442 — BAO — 5/30/79
LOGBOOK: UNIT # 6 BOOK 25 PP. 6-37 FUEL TYPE: #2 DIESEL FUEL

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	EQUIVALENT DIA. IN	HYDRAULIC DIA. IN	PERCENT OPEN AREA %	SPACING IN
1	DXE - 442	4070 J12	1.0 BY 3.0	0.85	0.03840	65.5	******
2	DXE - 442	4070 J1	1.0 BY 3.0	0.89	0.03840	65.5	0.25

	RUN NO.	HOURS ON FUEL	REYNOLDS # CHANNEL INLET	COMBUSTION EFFICIENCY %	HEAT RELEASE RATE KCAL/HR CM3 ATM	PERCENT ADIABATCITY %	EXHAUST GASES UHC PPM	CO PPM	NOx PPM	CO2 %	O2 %
1	146-14A	62.8	1943.3	99.95	98.95	91.57	0.	30.0	5.7	5.8	12.5
2	146-14B	92.0	1944.4	99.94	102.82	93.60	0.	32.0	5.7	5.5	11.9
3	146-14C	98.7	1943.9	99.94	102.01	91.85	0.	35.0	3.5	5.8	10.8
4	146-14D	111.6	1943.9	99.95	101.88	93.81	0.	30.0	3.6	5.6	11.2
5	146-14E	120.8	1943.9	99.94	102.58	92.28	4.0	20.0	4.0	5.6	10.6
6	146-14F	125.7	1943.9	99.95	101.61	90.54	2.0	20.0	3.6	5.4	13.0
7	146-14G	144.8	1943.9	99.95	101.61	91.08	2.0	20.0	4.5	5.5	12.7
8	146-14H	174.0	1943.9	99.95	102.31	91.63	2.0	20.0	4.4	5.6	12.5
9	146-14I	259.8	1943.3	99.79	98.80	94.88	5.0	100.0	5.5	6.1	13.3
10	146-14J	281.8	1943.3	99.93	98.67	92.08	4.0	25.0	4.5	5.9	13.2
11	146-14K	302.6	1944.6	99.74	101.46	90.72	1.0	145.0	4.6	5.8	13.1
12	146-14L	443.4	1944.6	99.87	102.97	88.25	1.0	70.0	4.3	6.2	12.5
13	146-14M	620.9	1944.6	99.04	102.10	91.37	10.0	525.0	4.6	5.6	13.2
14	146-14P	749.1	1944.3	98.49	100.92	93.27	15.0	820.0	5.1	5.6	13.5
15	146-14Q	848.4	1944.0	94.83	95.23	90.22	146.0	2500.0	5.1	5.5	13.5
16	146-14R	1014.5	1944.0	94.97	96.73	90.39	146.0	2420.0	5.6	5.9	13.3
17	146-14S	1029.0	1944.6	99.04	102.10	87.28	10.0	525.0	4.6	5.6	12.5
18	146-14T	1040.2	1943.3	99.71	101.71	89.59	0.	165.0	6.1	5.9	13.0
19	146-14U	1042.9	1943.3	99.68	100.98	89.37	0.	180.0	6.5	5.8	12.6
20	146-14V	1062.4	1943.3	99.94	100.28	92.08	0.	35.0	4.3	6.6	13.1

Appendix C: Computer Data Reduction of the Initial Parametric Test Results

RUN IDENTUN: PARAMATRIC STUDY FOR THE CATALYST CORE DXE-442 AFTER 24 HOUR AGING - BAO - 5/30/79
LOGBOOK: UNIT # 6 BOOK 25 PP. 8-11 FUEL TYPE: #2 DIESEL FUEL

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	EQUIVALENT DIA. IN	HYDRAULIC DIA. IN	PERCENT OPEN AREA %	SPACING IN
1	DXE - 442	4070 J12	1.0 BY 3.0	0.85	0.03840	65.5	******
2	DXE - 442	4070 J1	1.0 BY 3.0	0.89	0.03840	65.5	0.25

	RUN NO.	HOURS ON FUEL	FUEL/AIR RATIO	INLET P ATM	PRESSURE DROP %	INLET T C	OUTLET T C	MAX. T C	MAX. T LOCATION INCHES	REF. VELOCITY INLET FACE M/SEC
1	146-1P	60.0	.	5.0816	0.5915	360.0	360.0	360.0	0.250	13.999
2	146-1	60.0	.0211110	5.1156	0.9140	360.0	805.0	1020.0	4.250	13.906
3	146-2	60.0	.0237313	5.1156	0.9140	360.0	945.0	1130.0	4.250	13.906
4	146-3P	60.0	.	5.0816	0.3943	450.0	450.0	450.0	0.250	13.997
5	146-3	60.0	.0189009	5.0816	0.5258	450.0	855.0	1030.0	2.250	13.997
6	146-4	60.0	.0214235	5.1156	0.5223	450.0	930.0	1090.0	4.250	13.904
7	146-5	60.0	.0242285	5.2177	0.6401	450.0	1205.0	1210.0	2.250	13.632
8	146-6P	60.0	.	5.0136	0.9992	360.0	360.0	360.0	0.250	26.350
9	146-6	60.0	.0211209	5.0136	2.2049	360.0	670.0	670.0	0.250	26.350
10	146-7	66.0	.0240317	5.0136	2.1317	360.0	770.0	945.0	2.250	26.350
11	146-8	66.0	.0271555	5.0816	2.1032	360.0	860.0	1185.0	4.250	25.997
12	146-9P	60.0	.	1.1701	2.2835	360.0	360.0	360.0	0.250	22.565
13	146-9	60.0	.0211359	1.2041	3.6059	360.0	570.0	630.0	4.250	21.928
14	146-10	60.0	.0237556	1.2041	3.8833	360.0	700.0	860.0	4.250	21.928
15	146-11	60.0	.0271303	1.2041	3.8833	360.0	880.0	1140.0	4.250	21.928
16	146-12P	66.0	.	5.0136	0.6662	360.0	360.0	360.0	0.250	14.189
17	146-12	60.0	.0211110	5.0136	1.1991	360.0	830.0	1050.0	4.250	14.189
18	146-13	66.0	.0237313	5.0136	1.1991	360.0	930.0	1140.0	4.250	14.189
19	146-14P	60.0	.	3.7551	1.2541	360.0	360.0	360.0	0.250	18.944
20	146-14	60.0	.0264670	5.0000	1.4027	360.0	1140.0	1225.0	4.250	14.228

Appendix C (Continued)

RUN IDENTIFICATION: PARAMATRIC STUDY FOR THE CATALYST CORE DXE-442 AFTER 24 HOUR AGING — BAO — 5/30/79
LOGBOOK: UNIT # 6 BOOK 25 PP. 8-11 FUEL TYPE: #2 DIESEL FUEL

	CATALYST	ID.	DIMENSION DIA. X LEN. IN.	EQUIVALENT DIA. IN	HYDRAULIC DIA. IN	PERCENT OPEN AREA %	SPACING IN
1	DXE - 442	4070 J12	1.0 BY 3.0	0.85	0.03840	65.5	******
2	DXE - 442	4070 J1	1.0 BY 3.0	0.89	0.03840	65.5	0.25

	RUN NO.	HOURS ON FUEL	REYNOLDS # CHANNEL INLET	COMBUSTION EFFICIENCY %	HEAT RELEASE RATE KCAL/HR CM3 ATM	PERCENT ADIABATCITY %	EXHAUST GASES UHC PPM	CO PPM	NOx PPM	CO2 %	O2 %
1	146-1P	66.0	1893.2	0.	0.	0.	0.	0.	0.	0.	0.
2	146-1	66.0	1933.1	99.23	77.84	88.91	0.	345.0	3.6	4.4	14.0
3	146-2	66.0	1938.1	99.90	88.09	93.52	5.0	35.0	3.5	4.9	13.5
4	146-3P	66.0	1510.1	0.	0.	0.	0.	0.	0.	0.	0.
5	146-3	66.0	1538.6	99.22	61.41	88.34	4.0	300.0	3.2	4.0	14.5
6	146-4	66.0	1542.4	99.94	69.65	87.00	0.	25.0	3.7	4.4	14.2
7	146-5	66.0	1546.6	99.97	77.25	92.50	0.	15.0	4.3	5.2	13.2
8	146-6P	66.0	3515.7	0.	0.	0.	0.	0.	0.	0.	0.
9	146-6	66.0	3589.9	-	132.09	41.74	-	>5000.0	-	-	-
10	146-7	66.0	3600.2	84.87	143.60	70.26	900.0	5000.0	4.0	3.9	14.0
11	146-8	66.0	3611.2	99.13	187.00	89.00	0.	500.0	2.8	5.7	12.0
12	146-9P	66.0	702.6	0.	0.	0.	0.	0.	0.	0.	0.
13	146-9	66.0	717.5	-	110.01	36.33	-	>5000.0	-	-	-
14	146-10	66.0	719.3	-	125.35	60.67	-	>5000.0	-	-	-
15	146-11	66.0	721.7	98.72	156.93	84.21	11.0	700.0	5.2	5.1	12.7
16	146-12P	66.0	1893.2	0.	0.	0.	0.	0.	0.	0.	0.
17	146-12	66.0	1933.1	99.39	79.55	92.95	3.0	263.0	4.0	4.4	13.7
18	146-13	66.0	1938.1	99.94	89.92	94.73	0.	30.0	3.5	5.2	13.0
19	146-14P	66.0	1893.2	0.	0.	0.	0.	0.	0.	0.	0.
20	146-14	66.0	1943.3	99.94	100.56	95.44	0.	32.0	5.7	5.5	11.9

ENGELHARD INDUSTRIES

APPENDIX D

Appendix D: Computer Data Reduction of the Final Parametric Test Results

RUN IDENTITION: PARAMATRIC STUDY FOR THE CATALYST CORE DXE-442 AFTER 1000 HOUR AGING -BAO- 5/31/79
LOGBOOK: UNIT # 6 BOOK 25 PP. 36 - 39 FUEL TYPE: #2 DIESEL FUEL

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	EQUIVALENT DIA. IN	HYDRAULIC DIA. IN	PERCENT OPEN AREA %	SPACING IN
1	DXE - 442	4070 J12	1.0 BY 3.0	0.85	0.03840	65.5	******
2	DXE - 442	4070 J1	1.0 BY 3.0	0.89	0.03840	65.5	0.25

	RUN NO.	HOURS ON FUEL	FUEL/AIR RATIO	INLET P ATM	PRESSURE DROP %	INLET T C	OUTLET T C	MAX. T C	MAX. T LOCATION INCHES	REF. VELOCITY INLET FACE M/SEC
1	146-1P	1000.0	.	4.4694	1.6440	360.0	360.0	360.0	0.250	15.917
2	146-1	1000.0	.0211110	4.9456	1.8909	360.0	733.0	840.0	4.250	14.384
3	146-2	1000.0	.0237313	4.9456	2.0260	360.0	835.0	1060.0	4.250	14.384
4	146-3P	1000.0	.	3.7211	1.9746	450.0	450.0	450.0	0.250	19.115
5	146-3	1000.0	.0189009	4.9456	1.7558	450.0	760.0	930.0	4.250	14.382
6	146-4	1000.0	.0214235	4.9456	2.0260	450.0	821.0	1040.0	4.250	14.382
7	146-5	1000.0	.0242285	4.9456	2.7013	450.0	1045.0	1165.0	4.250	14.382
8	146-6P	1000.0	.	4.4013	5.6153	360.0	360.0	360.0	0.250	30.015
9	146-6	1000.0	.0211209	4.9456	5.2675	360.0	550.0	550.0	4.250	26.712
10	146-7	1000.0	.0240317	4.9456	6.2130	360.0	572.0	572.0	0.250	26.712
11	146-8	1000.0	.0271555	5.0136	5.9954	360.0	830.0	1160.0	4.250	26.350
12	146-9P	1000.0	.	1.2041	5.5476	360.0	360.0	360.0	0.250	21.928
13	146-9	1000.0	.0211359	1.2041	7.2118	360.0	540.0	555.0	2.250	21.928
14	146-10	1000.0	.0232672	1.2041	6.6571	360.0	535.0	548.0	4.250	21.928
15	146-11	1000.0	.0271303	1.2041	8.0440	360.0	782.0	1120.0	4.250	21.928
16	146-12P	1000.0	.	3.8231	2.1840	360.0	360.0	360.0	0.250	18.465
17	146-12	1000.0	.0211110	4.9796	1.6768	360.0	592.0	598.0	4.250	14.286
18	146-13	1000.0	.0237313	4.9456	1.8909	360.0	815.0	1065.0	4.250	14.384
19	146-14P	1000.0	.	3.7551	2.0457	360.0	360.0	360.0	0.250	18.944
20	146-14	1000.0	.0269120	4.9660	1.8831	360.0	910.0	1170.0	4.250	14.325

Appendix D (Continued)

RUN IDENTIFICATION: PARAMATRIC STUDY FOR THE CATALYST CORE DXE-442 AFTER 1000 HOUR AGING -BAU- 5/31/79
LOGBOOK: UNIT # 6 BOOK 25 PP. 36 - 39 FUEL TYPE: #2 DIESEL FUEL

	CATALYST	ID.	DIMENSION DIA. X LEN. IN.	EQUIVALENT DIA. IN	HYDRAULIC DIA. IN	PERCENT OPEN AREA %	SPACING IN
1	DXE - 442	4070 J12	1.0 BY 3.0	0.85	0.03840	65.5	******
2	DXE - 442	4070 J1	1.0 BY 3.0	0.89	0.03840	65.5	0.25

	RUN NO.	HOURS ON FUEL	REYNOLDS # CHANNEL INLET	COMBUSTION EFFICIENCY %	HEAT RELEASE RATE KCAL/HR CM3 ATM	PERCENT ADIABATICITY %	EXHAUST GASES UHC PPM	CO PPM	NOx PPM	CO2 %	O2 %
1	146-1P	1000.0	1893.2	0.	0.	0.	0.	0.	0.	0.	0.
2	146-1	1000.0	1933.1	-	72.07	64.66	-	>5000.0	-	-	-
3	146-2	1000.0	1938.1	91.58	83.53	85.01	310.0	3300.0	5.4	4.7	13.7
4	146-3P	1000.0	1510.1	0.	0.	0.	0.	0.	0.	0.	0.
5	146-3	1000.0	1538.6	-	55.66	73.11	-	>5000.0	-	-	-
6	146-4	1000.0	1542.4	94.19	67.90	80.20	145.0	2200.9	4.1	4.8	14.9
7	146-5	1000.0	1546.6	99.82	81.37	87.03	0.	92.5	5.1	5.1	13.7
8	146-6P	1000.0	3515.7	0.	0.	0.	0.	0.	0.	0.	0.
9	146-6	1000.0	3589.9	-	133.90	25.58	-	>5000.0	-	-	-
10	146-7	1000.0	3600.2	-	154.67	25.46	-	>5000.0	-	-	-
11	146-8	1000.0	3611.2	97.33	186.09	86.30	45.0	1400.0	4.7	5.3	13.0
12	146-9P	1000.0	702.6	0.	0.	0.	0.	0.	0.	0.	0.
13	146-9	1000.0	717.5	-	110.01	26.24	-	>5000.0	-	-	-
14	146-10	1000.0	719.0	-	122.49	23.23	-	>5000.0	-	-	-
15	146-11	1000.0	721.7	94.08	149.55	82.05	200.0	2800.0	5.3	5.2	12.9
16	146-12P	1000.0	1880.7	0.	0.	0.	0.	0.	0.	0.	0.
17	146-12	1000.0	1933.1	-	71.58	32.06	-	>5000.0	-	-	-
18	146-13	1000.0	1938.1	92.97	84.80	85.62	210.0	2900.0	6.8	4.8	13.6
19	146-14P	1000.0	1893.2	0.	0.	0.	0.	0.	0.	0.	0.
20	146-14	1000.0	1944.1	99.68	102.69	88.07	0.	180.0	6.5	5.8	12.6

APPENDIX E

Appendix E: Isothermal Pressure Loss Data

PRESSURE DROP DATA (ISOTHERMAL) : AT 0 HR AGING
LOG BOOK UNIT NO. 6 BOOK 17 PP. 46. 46 HCL 06/18/79 16:54EDT

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	NO	NCH	DIAMETERS EQUIVALENT DIA. IN	DIAMETERS HYDRAULIC DIA. IN	OPEN AREA %	AREA/VOL IN2/IN3	SPACING IN
1	DXE - 442	4070J-12	1.0 BY 3.0	256.	144.	0.8463	0.03840	65.5	68.2	0.25
2	DXE - 442	4070J-1	1.0 BY 3.0	256.	159.					

FOR CATALYST ONLY

	AIR FLOW SCFH	PRESS ATM	TEMP IN DEG K	REF VEL FT/SEC	UREF2/T	REYNOLD NO	TEMP OUT DEG K	PRESS DROP INCH WATER	PRESS LOSS PCT	FRICTION FACTOR
1	300.0	1.000	295.2	20.1	1.37	573.	295.2	3.30	0.81	0.02506
2	500.0	1.034	295.2	31.6	3.38	932.	295.2	6.70	1.59	0.01973
3	1000.0	1.088	295.2	59.3	11.92	1843.	295.2	18.90	4.27	0.01460
4	1500.0	1.136	295.2	84.7	24.32	2747.	295.2	23.10	5.00	0.00832
5	2000.0	1.306	295.2	98.0	32.52	3652.	295.2	68.00	12.79	0.01468
6	2500.0	1.408	295.2	113.4	43.59	4559.	295.2	03.30	18.03	0.01458
7	3000.0	2.020	295.2	94.8	30.44	5466.	295.2	81.60	9.93	0.01254
8	3000.0	3.041	295.2	63.0	13.43	5464.	295.2	59.80	4.83	0.01459
9	3000.0	4.061	295.2	47.1	7.53	5463.	295.2	43.50	2.63	0.01450

Appendix E (Continued)

PRESSURE DROP DATA (ISOTHERMAL) :AT 206 HRS AGING
LOG BOOK UNIT NO. 6 BOOK 25 PP. 16, 16

HCL 06/18/79 16:49EDT

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	NO	NCH	DIAMETERS EQUIVALENT DIA. IN	DIAMETERS HYDRAULIC DIA. IN	OPEN AREA %	AREA/VOL IN2/IN3	SPACING IN
1	DXE - 442	4070J-12	1.0 BY 3.0	256.	144.	0.8463	0.03840	65.5	68.2	0.25
2	DXE - 442	4070J-1	1.0 BY 3.0	256.	159.					

	AIR FLOW SCFH	PRESS ATM	TEMP IN DEG K	REF VEL FT/SEC	UREF2/T	REYNOLD NO	TEMP OUT DEG K	PRESS DROP INCH WATER	PRESS LOSS PCT	FRICTION FACTOR
FOR CATALYST ONLY										
1	500.0	1.136	297.2	29.7	2.96	951.	297.2	6.50	1.41	0.01993
2	1000.0	1.204	297.2	54.6	10.04	1857.	297.2	17.68	3.61	0.01475
3	1500.0	1.340	297.2	72.8	17.81	2752.	297.2	36.72	6.73	0.01503
4	2000.0	1.544	297.2	83.7	23.56	3646.	297.2	61.20	9.74	0.01593
5	2500.0	1.748	297.2	92.1	28.55	4546.	297.2	89.76	12.62	0.01652
6	3000.0	2.088	297.2	92.4	28.73	5447.	297.2	18.32	13.92	0.01786
7	3000.0	3.041	297.2	63.4	13.53	5443.	297.2	61.20	4.95	0.01480
8	3000.0	4.061	297.2	47.5	7.58	5441.	297.2	42.16	2.55	0.01397

Appendix E (Continued)

PRESSURE DROP DATA (ISOTHERMAL) : AT 729 HRS AGIN
LOG BOOK UNIT NO. 6 BOOK 25 PP. 23, 27 HCL 06/18/79 16:44EDT

	CATALYST	ID.	DIMENSION DIA. X LEN. IN	NO	NCH	DIAMETERS EQUIVALENT DIA. IN	DIAMETERS HYDRAULIC DIA. IN	OPEN AREA %	AREA/VOL IN2/IN3	SPACING IN
1	DXE - 442	4070J-12	1.0 BY 3.0	256.	144.	0.8463	0.03840	65.5	68.2	0.25
2	DXE - 442	4070J-1	1.0 BY 3.0	256.	159.					

FOR CATALYST ONLY

	AIR FLOW SCFH	PRESS ATM	TEMP IN DEG K	REF VEL FT/SEC	UREF2/T	REYNOLD NO	TEMP OUT DEG K	PRESS DROP INCH WATER	PRESS LOSS PCT	FRICTION FACTOR
1	1000.0	1.204	297.2	56.0	10.55	1903.	297.2	20.40	4.16	0.01612
2	1500.0	1.340	297.2	73.6	18.24	2785.	297.2	34.00	6.24	0.01366
3	2000.0	1.578	297.2	82.4	22.83	3669.	297.2	55.76	8.68	0.01482
4	2500.0	1.884	297.2	85.7	24.72	4560.	297.2	92.48	12.06	0.01834
5	3000.0	2.224	297.2	86.9	25.40	5455.	297.2	25.12	13.82	0.02008
6	3000.0	3.041	297.2	63.5	13.55	5447.	297.2	50.32	4.07	0.01226
7	3000.0	4.061	297.2	47.5	7.59	5443.	297.2	36.72	2.22	0.01220
8	3000.0	2.973	297.2	64.8	14.15	5441.	297.2	55.04	4.55	0.01308
9	3000.0	3.993	297.2	48.3	7.84	5440.	297.2	36.01	2.22	0.01177